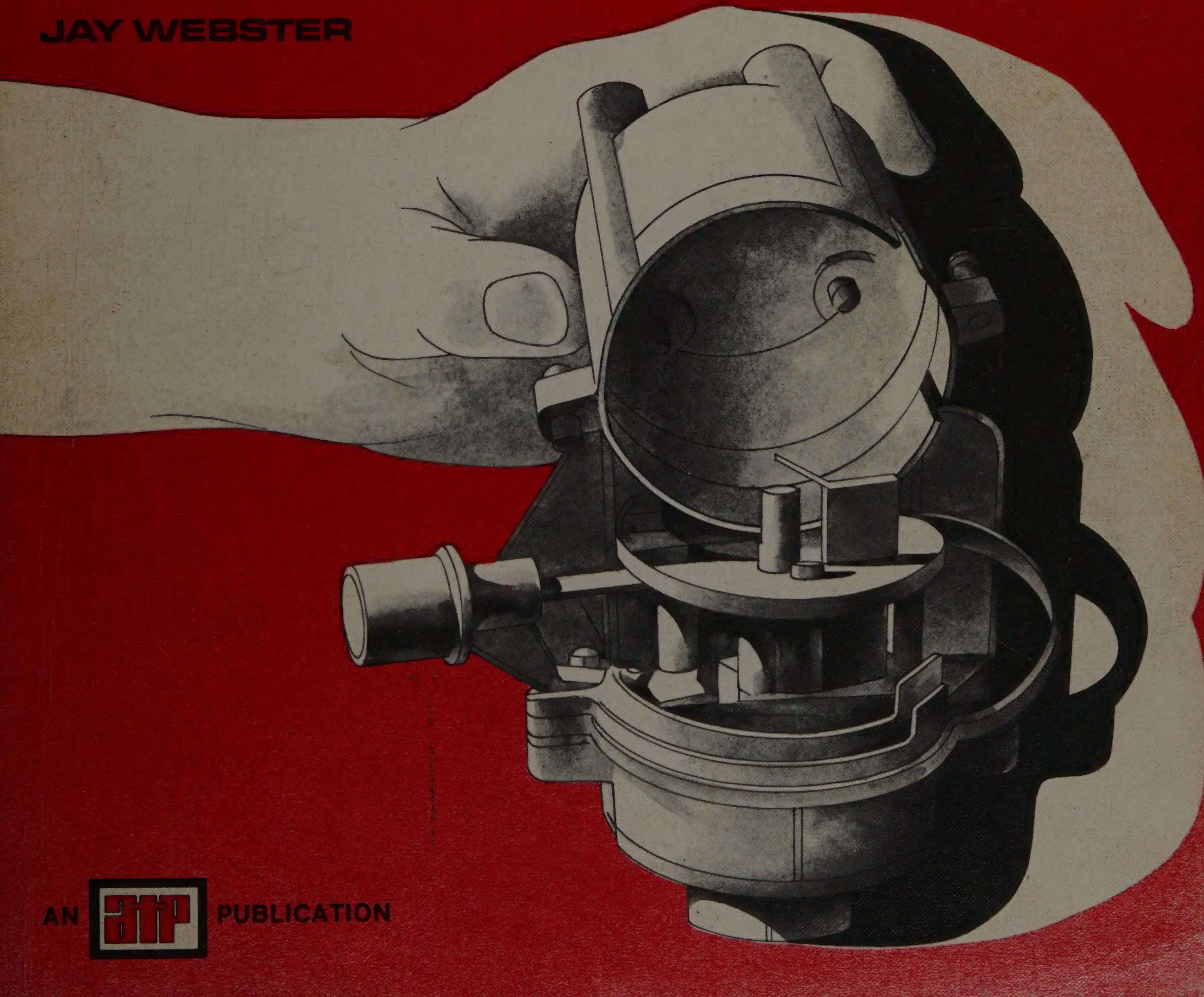
AUTOMOTIVE TUNE-UP

JAY WEBSTER



AN atp PUBLICATION

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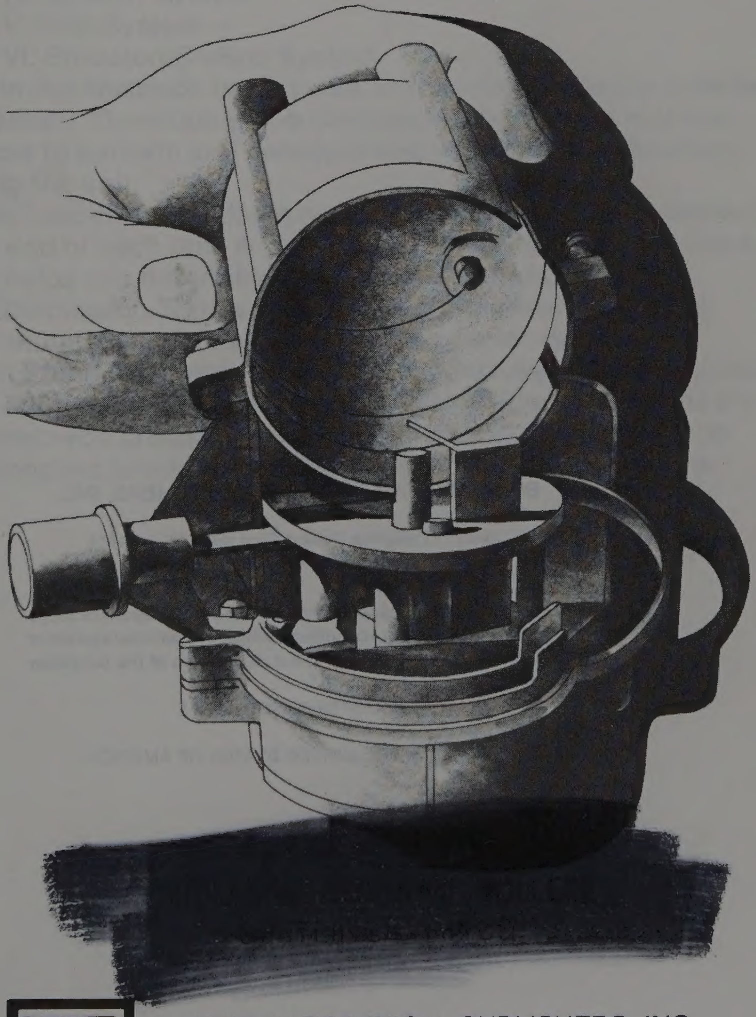

AMERICAN TECHNICAL PUBLISHERS, INC.
ALSIP, ILLINOIS 60658

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1983

37607

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Library of Congress Catalog Card Number 82-84715
ISBN: 0-8269-0256-1

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123456789-83-987654321

PRINTED IN THE UNITED STATES OF AMERICA

NOTE TO THE STUDENT

Automotive Tune-Up is designed to help you train as a specialist mechanic in the area of automotive tune-up.

The textbook covers the four areas serviced during a tune-up: the engine, the ignition system, the fuel system, and the emission control system. Some units explain how these systems work (operation), others explain how to determine what is wrong with them (troubleshooting or diagnosing) and still others explain how to repair the systems (servicing). The textbook is divided into six sections:

- Section I: General Information
- Section II: Basic Engine Operation and Troubleshooting
- Section III: Starting and Charging Systems
- Section IV: Ignition System
- Section V: Fuel System
- Section VI: Emission Control System

Each unit in this textbook begins with an introduction to the material and a list, headed "Developing Job Competencies," of jobs that you should be able to perform and concepts that you should understand after studying the unit.

"Key Terms" appear as boldface words in each unit and are defined again at the end of each unit. A set of "Self-Check" questions at the end of each unit helps you determine if you have met the learning objectives. "Discussion Topics and Activities" are provided for the person who wants to study the unit's topic in greater depth. "Certification Practice" questions similar to those used on the National Institute for Automotive Service Excellence (NIASE) examinations are provided to help you prepare for a certification test. The answers to these questions are provided immediately following the questions.

ACKNOWLEDGMENTS

American Motors Corporation

Belden Corporation

Robert Bosch Sales Corporation

Cadillac Motor Car Division
General Motors Corporation

Chevrolet Motor Division
General Motors Corporation

Chrysler Corporation

Clayton Manufacturing Company

Delco Remy Division
General Motors Corporation

Delta Products, Inc.

Ford Motor Company

Marquette Products
Automotive Division of Applied Power, Inc.

National Safety Council

NGK Spark Plugs U.S.A. Inc.

C. E. Niehoff & Co.

Nissan Motor Corporation in U.S.A.

Oldsmobile Division
General Motors Corporation

Sun Electric Corporation

United Technologies
Hamilton Test Systems

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SECTION I

General Information

Unit 1. Introduction to Automotive Tune-up
Unit 2. Working Safely
Unit 3. Fundamentals of Electricity and Electronics
Unit 4. Tune-up Tools and Equipment
Unit 5. Looking up Tune-up Specifications

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Unit 1 INTRODUCTION TO AUTOMOTIVE TUNE-UP

An automotive tune-up is the adjustment, service, and replacement of automotive components to achieve four goals:

1. Maximum engine power for safety, reliability, and drivability, or performance.
2. Highest possible fuel mileage.
3. Lowest possible level of harmful emissions.
4. Compliance with manufacturer's specifications.

DEVELOPING JOB COMPETENCIES

When you finish reading and studying this unit, you should be able to:

- List the goals of a tune-up.
- Describe a tune-up procedure.
- Identify the systems which are serviced during a tune-up.
- Describe the career opportunities in the tune-up field.
- Explain how to prepare for a career in the tune-up field.

THE TUNE-UP PROCEDURE

A tune-up involves four steps:

1. Determine which vehicle components require periodic service, and check their condition. The engine should be checked first.

2. Diagnose (identify) problems by performing an organized test sequence called **troubleshooting**, sometimes referred to as *diagnosing*. This will help you determine which components are not operating properly.

3. Service, adjust, or replace components as required.

4. Recheck to make sure the problem is corrected.

A complete tune-up involves four basic vehicle areas: the **engine**, the **ignition system**, the **fuel system**, and the **emission control system**. A well-tuned engine is one that has all its related systems working together to provide maximum power, maximum fuel economy, and the lowest possible level of emissions.

The first step in any tune-up is to determine that the engine is in satisfactory condition. An engine with worn internal components, such as piston rings or valves, cannot develop maximum power. Therefore, any additional work on the fuel, ignition, or emission systems will not improve power, mileage, or emission levels.

The purpose of the ignition system is to provide a precisely timed high-voltage spark to ignite the *air-fuel mixture* in each cylinder when it is ready for a power stroke. Ignition system diagnosis and service are part of every tune-up. On older vehicles, a great deal of parts replacement was necessary to service the ignition system. Late-model electronic ignition systems have shifted the emphasis from parts replacement to adjustment.

The fuel system is designed to store a certain amount of fuel, to deliver the fuel to the engine, and to mix the fuel with air in the proper amounts (air-fuel mixture) for efficient burning in the cylinder. Proper fuel system operation is receiving an increasing emphasis in tune-up procedures. Not only does the fuel system affect engine performance, but it has become increasingly important for high mileage and low emissions.

Air pollution is caused when certain *hydrocarbons* (abbreviated HC) and *oxides of nitrogen* (abbreviated NO_x), both from automobile exhaust and other sources, react in the presence of sunlight. Air pollution is a major concern because many pollutants, both gases and solid particles, are dangerous to health.

The hazards of these pollutants have caused the federal government to specify the amount of pollution that automobiles can emit. If the vehicle manufacturer cannot meet these requirements, the vehicle cannot be sold. As the regulations have become more strict, the emission control equipment on the automobiles has become more complicated. Automobile owners are required to maintain their vehicles so that emission control devices keep emissions low. The job of the tune-up technician is to know the legal requirements as well as the mechanical systems to service for emission control.

A CAREER AS A TUNE-UP TECHNICIAN

As fuel mileage and emission standards become more stringent, there will be an increasing need for technicians who can troubleshoot and service complex systems. The tune-up technician performs preventative maintenance, troubleshoots problems, disassembles components, makes necessary repairs, and reassembles components.

A tune-up technician may work in an automotive **dealership** or an **independent garage**. An automotive dealership is a business facility organized to sell and service new and used automobiles. In a dealership, a number of service personnel prepare new automobiles for sale. They check and adjust them to make sure they are operating according to specifications. Since the warranty on new vehicles specifies that they should be serviced and inspected at an authorized dealership, a lot of tune-up service is done at dealerships.

An independent garage is an independently owned service facility that may service any type of automobile and is not affiliated with any automotive manufacturer. Independent garage operations may be organized to service the total vehicle or just one specific area, such as a tune-up. As vehicle warranties expire, opportunities to service automobiles in independent garages increase.

There are a number of different service jobs in both dealerships and independent garages. An automobile **detailer** prepares automobiles for sale or delivery to a customer. This involves washing and waxing the outside of the automobile as well as cleaning and vacuuming the inside.

The job of the **lubrication specialist** is to perform all lubrication activities. This includes lubricating chassis components; draining and replacing engine oil; and checking fluid and oil levels in the transmission, differential, power steering, and brake systems. He or she must know exactly where lubrication is required and what kinds of lubricants to use. In addition, the lubrication specialist may be required to make a thorough inspection of other parts such as the battery, radiator, radiator hoses, fan belts, exhaust system, tires, and brakes.

A **line mechanic** may service any part of the automobile and will perform light repairs and heavy repairs. Light repair usually refers to minor service jobs such as installation of accessories, predelivery inspection of new automobiles, and replacement of parts (such as fan belts and radiator hoses). Heavy repair involves measuring, disassembling, machining, reassembling, and adjusting complicated components such as engines, transmissions, and differentials. This means that the line mechanic must learn about many different components and systems. That person must also keep up-to-date on industry changes in these components and systems.

Because the automobile has become more complex, it is more difficult for the line mechanic to keep up with all the changes. As a result, many mechanics now work in only one area of service and are called **specialist mechanics.** The specialist mechanic usually has advanced training and a great deal of experience in a particular area. The tune-up is rapidly becoming an area of specialization.

Hard-working and experienced mechanics may advance into a supervisory position such as shop supervisor, service writer, or service manager. The shop supervisor is in charge of a number of mechanics. He or she schedules the work and makes sure it is done correctly. The service writer is usually the first person to meet the customer. He or she discusses the automobile problem with the customer and then prepares the cost estimates and billings required to get the problem corrected. The service manager is responsible for the entire service department in a large garage or dealership.

PREPARING FOR A CAREER

If you are interested in automobiles, like working on them, and enjoy studying about them, you should consider a career in automotive tune-up. In making any kind of career choice, you must be sure of your interests. You must also be certain that you want to do the kind of work involved in that career. The best way to find out while you are still in high school is by working in a cooperative program, working part-time, or working full-time during summer break from school.

If you are already an automotive mechanic, you might consider retraining as a tune-up technician. The tune-up technician does precision work.

There are many things you can do to get ready for a career. First, learn all you can about different careers. Talk to people who work in your areas of interest. Find out the good and bad things about their jobs. Read about different occupations in your school or public library, and talk to your teachers and school counselor.

Different careers require different aptitudes. Your teachers and school counselor can help you find out if you have the aptitude for your career choice.

If you decide to become a tune-up technician, the next step is to get the necessary training and experience. This normally means a formal automotive training program, on-the-job apprenticeship training, or a combination of the two. There are also training opportunities in high schools, community colleges, trade schools, and the armed forces.

KEY TERMS

Dealership: A business facility organized to sell and service new and used automobiles.

Detailer: A service worker who cleans an automobile to prepare it for sale or delivery to a customer.

Emission control system: One of the systems serviced during a tune-up. A system designed to reduce pollution from the automobile.

Engine: The first area checked in a tune-up. It must be in satisfactory condition before its systems can be worked on.

Fuel system: One of the systems serviced during a tune-up. The fuel system stores, delivers, and mixes air with fuel for burning in the engine.

Ignition system: One of the systems serviced during a tune-up. The ignition system provides a series of precisely timed sparks to ignite the air-fuel mixture in the engine's combustion chamber.

Independent garage: An independently owned service facility that may service any type of automobile.

Line mechanic: A service worker who may service any part of the automobile.

Lubrication specialist: The service worker responsible for performing all lubrication activities.

Specialist mechanic: A mechanic who works in only one area of service.

Troubleshooting: An organized test sequence used to diagnose a problem. It is also referred to as diagnosing.

SELF-CHECK

1. List the four goals of a tune-up.
2. What are the four steps involved in a tune-up?
3. What four basic vehicle areas are involved in a tune-up?
4. Why should the engine be checked first in a tune-up?
5. What is the purpose of the ignition system?
6. What is the purpose of the fuel system?
7. What is the purpose of the emission control system?
8. What is a dealership?
9. What is an independent garage?
10. What types of repairs does a line mechanic do?

DISCUSSION TOPICS AND ACTIVITIES

1. Compare the tune-up procedures for a late-model vehicle with the tune-up procedures for a ten-year-old vehicle. What are the differences?
2. Information on occupations can be found in several books. One of them is entitled *Occupational Handbook*. Find this book, or one similar, in the library and research a career that interests you.

CERTIFICATION PRACTICE

1. A line mechanic works in:
   A. A dealership
   B. An independent garage
   C. Both A and B
   D. Neither A nor B
2. A mechanic who works in only one service area, such as tune-up, is called a:
   A. Line mechanic
   B. Specialist mechanic
   C. Detailer
   D. None of the above
3. The goal of a tune-up is:
   A. Maximum engine power
   B. Highest possible fuel mileage
   C. Lowest possible level of emissions
   D. All of the above
4. During a tune-up, the technician:
   A. Determines what components require service
   B. Troubleshoots (diagnoses)
   C. Services, adjusts, and replaces components
   D. All of the above
5. A tune-up involves the servicing of the:
   A. Ignition system
   B. Fuel system
   C. Emission control system
   D. All of the above

ANSWERS

1: C, 2: B, 3: D, 4: D, 5: D

Unit 2 WORKING SAFELY

When doing a tune-up, you will be working with a wide variety of tools and equipment. There are safety hazards in using some of these tools and equipment. Working on certain areas of a car, such as the fuel system, electrical system, and exhaust system, also involves some safety hazards.

DEVELOPING JOB COMPETENCIES

When you finish reading and studying this unit, you should be able to:

- List and describe basic shop safety procedures.
- Describe the safety precautions necessary when running a car in the shop.
- Describe the safety precautions necessary when working on a fuel system.
- Describe the hazards involved in working with batteries.
- Describe how to avoid electrical shocks from the ignition secondary voltage.
- Describe the safety precautions necessary when cleaning automotive parts.

BASIC SHOP SAFETY PROCEDURES

1. Wear proper clothing at all times. Avoid dangling shop coats, loose sleeves, and hanging neckties that can become caught in the fan or other moving engine parts. Safety shoes should always be worn.

2. Remove all jewelry and metal from your body before beginning work. Rings and watches have been the cause of many painful burns and even lost fingers and hands.

3. Keep your work area clean, and put tools away when the job is finished.

4. Do not leave anything lying around when you are working on a vehicle — especially a creeper. Keep the creeper under the vehicle or store it in an upright position.

5. Never get underneath a vehicle that is not properly supported by safety stands. This is one of the most common *fatal* errors made every year.

6. Always use the correct tools and equipment for the job. Know the correct procedure for the job before you begin. Also, follow the manufacturer's recommended procedures when using any shop equipment or installing parts and accessories.

7. Always wear **eye protection** (goggles or face shield) whenever you work on the car or with shop equipment (Figure 2-1).

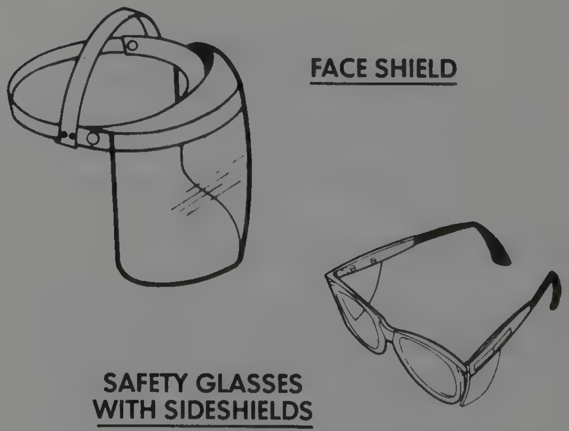

Figure 2-1. Wear appropriate eye protection when you work on the car or with shop equipment.

8. Give the job your full attention — do not be distracted by what someone else is doing.

9. Many accidents are caused by careless use of hand tools. Greasy tools can slip out of the hand, fall onto a moving part of the engine, and be ejected with great force, resulting in serious injury. Tools with sharp edges cause cuts if not handled properly.

RUNNING A CAR IN THE SHOP

During a tune-up, you will have to run the car's engine to check for problems with the various systems and to check your repairs. You should observe these safety precautions when you work on a running engine.

1. Never run a vehicle inside the shop without hooking up the exhaust elimination system. Exhaust gases contain **carbon monoxide** (abbreviated CO) and can cause carbon monoxide poisoning. Carbon monoxide is a colorless, odorless gas and therefore is hard to detect. It is present in the engine exhaust. If an engine is operated without proper ventilation, carbon monoxide may build up to dangerous levels.

2. Make sure the emergency brake is set before leaving the vehicle. Some idle-speed adjusting jobs may require that an automatic transmission be set in DRIVE rather than PARK. To prevent the car from moving, always block the wheels and be sure the emergency brake is set.

3. Do not crawl under a car when someone is working topside or when the car is running.

4. Do not choke an engine by placing your hand over the carburetor air horn.

5. If there is no fuel in the carburetor, do not pour gasoline into the carburetor while cranking the engine. Instead, pour a small amount of gasoline into the carburetor, replace the air cleaner, and then crank the engine. This procedure will prevent a fire and possible injury or death.

6. Never perform any under-the-hood service, such as checking oil, belts, or battery, with the engine running.

7. Be cautious of hot manifolds and moving engine parts if working under the hood.

8. Many cars now use electric cooling fans. These fans can start up at any time — some of them even when the engine is not running. Keep clear of electric fans.

9. Do not operate an engine at high RPM (revolutions per minute) for long periods of time.

10. When testing an engine at high RPM, wear face and ear protection.

11. Avoid standing in front of or behind an automobile when the engine is running.

DRIVING VEHICLES

Moving vehicles are a potential hazard around the shop. Observe these safety precautions:

1. Check for tools and other equipment which might be on the floor before driving a vehicle. Walk around the area to be sure it is cleared.

2. When test-driving a vehicle or even riding in one, wear the safety belt.

3. Never travel faster than 5 MPH (miles per hour) in the shop area.

WORKING ON FUEL SYSTEMS

When doing a tune-up, you will be servicing the vehicle's fuel system. This means working around gasoline. Many gasoline fires and explosions occur every year. Be extremely cautious when working with gasoline.

The important fact to remember about gasoline is that liquid gasoline itself is not the real danger. The real danger is the **gasoline vapor** — the gas given off by the liquid gasoline. To avoid gasoline fires and explosions in the shop, you have to prevent gasoline vapors from escaping.

Vapors are heavier than air and settle in low spots along the floor — for example, in lubrication and alignment pits. Any source of ignition, such as a lighted match or cigarette, or even an arc from an electric switch or motor, can ignite the gasoline vapors. Vapors may also be carried by air movement (circulation) a considerable distance and then ignited by a space heater or pilot light on a water heater. Avoid build-up of gasoline vapors in the shop, even if you think there are no sources of ignition.

The safety precautions for handling gasoline are simple:

1. Gasoline should be used ONLY as a source of energy for a gasoline engine. It should never be used for any other purpose.

2. Never use gasoline to clean anything, especially your hands. Use appropriate solvents to clean automotive parts and tools.

3. Clean up gasoline spills immediately. If gasoline is spilled inside the shop, open the doors and windows to get plenty of ventilation. Avoid any type of fire or spark (including sparks from electric switches), until the vapors are dispersed. Small spills can be wiped up with rags and the rags disposed of properly (see Rule 9 in this list). Large spills should be thoroughly flushed with water.

4. Fuel system work should be done outdoors or in a well-ventilated area. When draining the carburetor or a fuel line, catch the gasoline in a container.

5. Gasoline-soaked clothes should be removed immediately and allowed to dry. Drying should be done away from any source of ignition. Do not work in gasoline-soaked clothes!

6. Store gasoline only when absolutely necessary and only in an approved safety can (Figure 2-2).

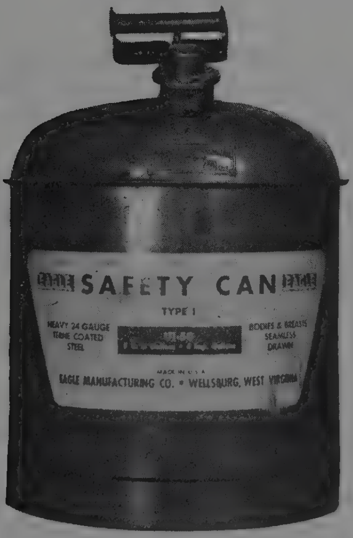
SAFETY CAN
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Figure 2-2. Gasoline must be stored in a safety can.

7. Never smoke around gasoline. Most repair shops have approved smoking areas. As stated earlier, gasoline can be very dangerous if allowed to vaporize around any source of ignition, including cigarettes, appliance pilot lights, and electric switches.

8. Do not remove a fuel injection line without first bleeding the system (relieving the pressure). Fuel lines can be pressurized even when the engine is turned off.

9. Place rags containing oil, gasoline, paint, solvents, and other combustibles in designated (approved) metal containers (Figure 2-3).

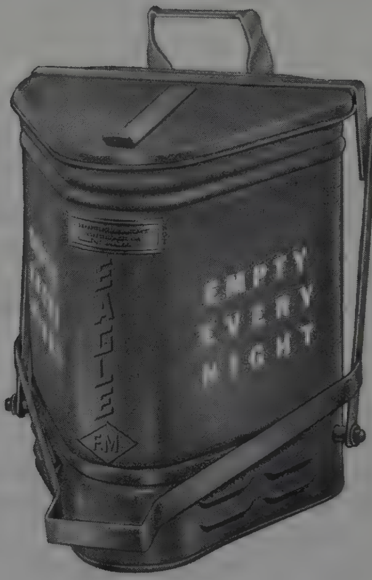


Figure 2-3. Gasoline-soaked rags must be stored in a covered metal container.

WORKING WITH BATTERIES

The battery is potentially one of the most dangerous items in the shop. It gives off explosive **hydrogen gas** (hydrogen is abbreviated H), especially when being charged. **Battery electrolyte** is an acid solution used in battery cells. It can cause damage to eyes and skin, as well as clothing.

Basic Safety Precautions

1. When handling batteries, avoid smoking or causing any source for ignition, such as a spark or open flame.

2. Rings, identification bracelets, and watches should never be worn. These can complete electrical circuits, causing a current to flow through them. This current can heat a ring to a high temperature almost instantaneously, which can cause a severe burn.

3. Chemical goggles and neoprene gloves (Figure 2-4) should always be worn when handling batteries.

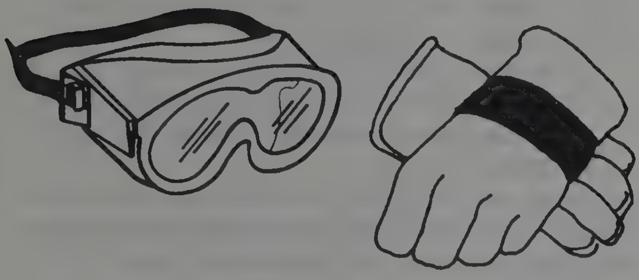


Figure 2-4. Wear neoprene gloves and eye protection when servicing a battery. (Courtesy of National Safety Council)

4. Stand at arm's length when removing battery caps.

5. If you get acid or battery corrosion on your skin, wash the area thoroughly. If you get acid in your eyes, wash them with water for 15 minutes and consult a physician immediately.

Charging a Battery

You may have to replace an old battery with a new one. This requires putting an initial charge on the battery (Figure 2-5). Observe these safety precautions:

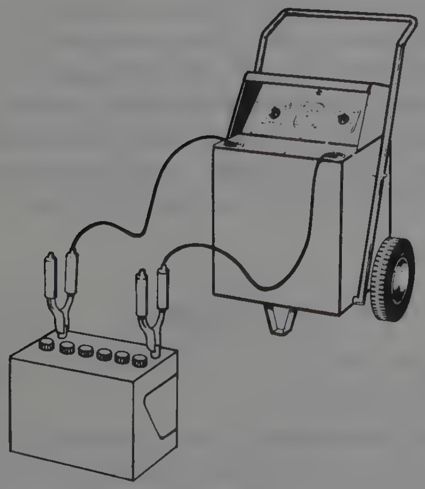


Figure 2-5. Exercise caution when charging a battery. (Courtesy of Ford Motor Company)

1. Follow the instructions of the battery charger manufacturer for setting charging rate and time.

2. Remove battery caps and adjust fluid level if applicable. Be sure that vent holes in caps are open.

3. To prevent sparks, connect and disconnect charger clips only with charger in OFF position.

4. Use charger only in a well-ventilated area or in a room designed for battery charging.

Jump-starting a Battery

You may have to jump-start a vehicle with a dead or discharged battery by using a booster battery (Figure 2-6). To minimize explosion hazards and prevent damage to the alternator, observe the following jump-starting procedure:

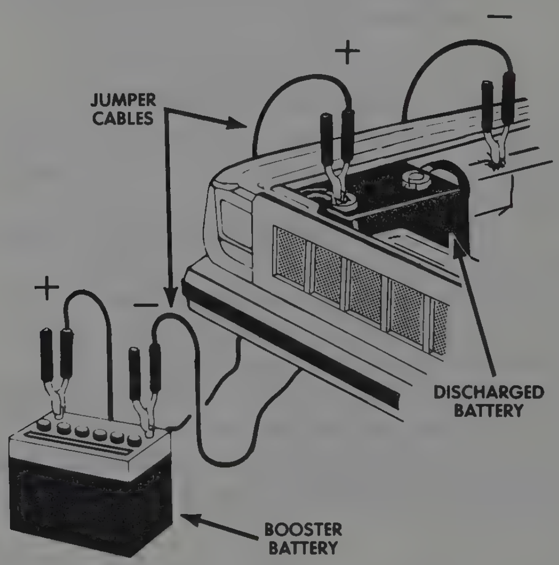


Figure 2-6. Jump-starting a discharged battery with a booster battery.

WARNING: Wear eye protection when jump-starting. If the booster battery is in a vehicle, make sure the vehicles are not touching. Set the parking brakes and put the transmission in PARK or NEUTRAL. Turn off all electrical loads.

1. Check to be sure the battery electrolyte is not frozen. **WARNING: Never try to jump-start a frozen battery. Always double-check the polarity before making connections. Do not lean over batteries when making connections. Keep head and body away as much as possible in case of a battery explosion.**

2. Connect the positive (+) jumper cable to the positive (+) terminal of the discharged (dead) battery. Connect the other end of the positive (+) cable to the positive (+) terminal of the booster battery.
3. Connect the negative (−) jumber cable to the negative (−) terminal of the booster battery; then, to prevent a spark near the battery, connect the other end of the negative (−) jumper cable to a good ground on the engine. Avoid making the connection near the discharged battery.
4. Start the disabled engine.
5. Remove the jumber cables in the following sequence:
    a. Negative (−) cable from engine.
    b. Negative (−) cable from negative terminal of booster battery.
    c. Positive (+) cable from booster battery.
    d. Positive (+) cable from battery of disabled car.

Filling a Dry-charged Battery

You may have to fill a dry-charged battery with electrolyte. When doing this job, observe these safety precautions:

1. Never fill a battery with electrolyte when the battery is in the car.
2. Place the battery on the floor before filling it with electrolyte. This prevents the acid from getting on you or the vehicle.
3. Filling and charging operations should be performed near an eyewash facility.
4. Always wear protective chemical goggles or a face shield and gloves when filling the battery.

WORKING WITH HIGH VOLTAGE

During tune-up work, you will be servicing the ignition system. The ignition secondary system develops 30,000 V (volts) or more. The low current associated with this voltage does not have enough amperage to be fatal to a person in good health. The main danger is that the jolt (electrical shock) may cause you to "jump" into a moving part or fall and hurt yourself.
WARNING: Always use insulated pliers to handle a spark plug cable or coil wire (high-voltage lead).

CLEANING CARBURETOR PARTS

When doing carburetor service, clean the parts in a cleaning tank. The solvents used for cleaning can cause skin irritation, and the vapors may be harmful if breathed excessively. Observe these safety precautions when cleaning parts:

1. Wear eye protection.
2. Clean parts only in the cleaning tank.
3. Do not store solvent in your work area.
4. Wear protective gloves and an apron when handling solvent.
5. Avoid breathing solvent vapors. A respirator and face shield should be used when washing parts with a pressurized spray.
6. Wash hands and arms with soap and water when finished at the cleaning tank.
7. Keep cleaning tank closed when not in use.

USING COMPRESSED AIR

Compressed air is available in most automotive shops to inflate tires, operate pneumatic tools, and spray paint. Before the dangers associated with compressed air were realized, it was common practice for a mechanic to use compressed air to blow solvent off parts that had been cleaned. The problem is that dirt and solvent blown by compressed air can cause considerable injury. Foreign particles can be forced into the skin or into the eyes or they may be inhaled. **WARNING: To be safe, avoid the use of compressed air to blow off parts whenever possible. Place parts washed in solvent on a clean rag to dry. There may be an occasion to use compressed air in fuel system work. It may be necessary to force air through fuel system parts to clean small passages. If you must use compressed air to clean out a passage, wear eye protection and a respirator to prevent injuries.**

KEY TERMS

Battery electrolyte: The acid solution used in battery cells.

Carbon monoxide: The colorless, odorless, poisonous gas that is present in a car's exhaust. It is abbreviated CO.

Eye protection: Goggles or face shields used to prevent injury to the eyes.

Gasoline vapor: A gas given off by liquid gasoline. It is extremely explosive.

Hydrogen gas: A gas given off by a battery. It is extremely explosive. It is abbreviated H.

SELF-CHECK

1. List five basic shop safety procedures.
2. How can accidents be caused by hand tools?
3. List five safety precautions to observe when running a car in the shop.
4. How can a car be prevented from moving when it is running?
5. What is the proper procedure for starting an engine with an empty carburetor?
6. What is the main hazard when working near an electric cooling fan?
7. List five safety precautions to observe when handling gasoline.
8. List four safety precautions to observe when working with batteries.
9. Explain the procedure for jump-starting a battery.
10. How can you avoid electrical shock from the ignition system?

DISCUSSION TOPICS AND ACTIVITIES

1. Make up a safety checklist and determine how safely you work.
2. Look for safety hazards in your home and garage. Correct any that you find.

CERTIFICATION PRACTICE

1. When working in the shop:
   A. Wear proper clothing
   B. Remove all jewelry
   C. Keep work area clean
   D. All of the above
2. When running a car in the shop:
   A. Hook up an exhaust elimination system
   B. Set the emergency brake
   C. Block the wheels
   D. All of the above
3. When working on the fuel system:
   A. Clean up gasoline spills immediately
   B. Work in a well-ventilated area
   C. Catch gasoline in a container when draining a fuel line
   D. All of the above
4. When working with batteries:
   A. Wear eye protection
   B. Remove all jewelry
   C. Wear neoprene gloves
   D. All of the above
5. When cleaning a carburetor in a cleaning tank:
   A. Wear protective gloves
   B. Wear eye protection
   C. Keep tank closed
   D. All of the above

ANSWERS

1: D, 2: D, 3: D, 4: D, 5: D

Unit 3 FUNDAMENTALS OF ELECTRICITY AND ELECTRONICS

Many of the components and systems that a tune-up technician must troubleshoot and service operate electrically or electronically. Many of the testing instruments used during a tune-up are electrical or electronic. A tune-up technician must understand the principles of electricity and electronics in order to operate these electrical testing instruments.

DEVELOPING JOB COMPETENCIES

When you finish reading and studying this unit, you should be able to:

- Describe an atom and its relationship to electron flow.
- Explain the difference between insulators and conductors.
- Describe the relationship between amperage, voltage, and resistance.
- List and describe the basic parts of a circuit.
- Use a wiring diagram to trace a circuit.
- Explain magnetism and its relationship to electricity.
- Describe the types and sizes of automotive wires.

MATTER

In order to understand what electricity is and how it works, you must first understand what the scientists call "the composition of matter."

Everything in the universe consists of matter. Scientists define **matter** as "that of which any physical object is composed." Physical objects are anything that take up space and have weight. You and the chair you sit in, the food you eat, the air you breathe, and anything that you can see and touch are all physical objects composed of matter. Matter may be in the form of a *solid*, a *liquid*, or a *gas* (vapor). Thus, ice, water, and steam are examples of matter in all three forms (Figure 3-1).

All matter is composed of chemical building blocks called *elements*. Nature has provided over 100 elements which combine in countless different combinations to form the different kinds of matter found on Earth.

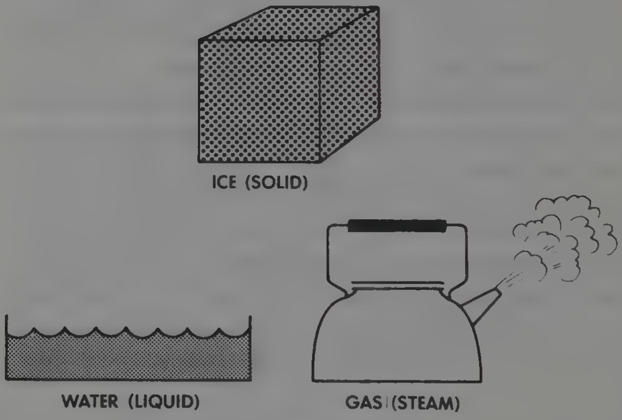


Figure 3-1. Matter may take the form of a solid, liquid, or gas. (Courtesy of Delco Remy, Division of General Motors Corporation)

Atoms

An **atom** is the smallest particle into which an element can be divided and still retain its characteristics as an element. Atoms are so small that they cannot be seen even with the most powerful microscopes.

Atoms are made up of small particles which have positive (+) and negative (−) electrical charges, called *protons* and *electrons*, respectively. The words *positive* and *negative* (referred to as *polarity*) mean only that the two charges are unlike each other — that is, they are completely opposite, just as black and white or night and day are opposite to each other. Atoms also contain *neutrons*. Figure 3-2 shows the structure of a carbon atom. The center or *nucleus* of a carbon atom consists of 6 protons and 6 positive-negative charges (neutrons). Because neutrons contain a positive (+) charge and a negative (−) charge, they balance each other out and are said to have a neutral charge. Since the protons have positive (+) charges and the neutrons are neutral, the positive (+) charges in the nucleus are in the majority. Therefore, the nucleus itself is positive (+). Lastly, the carbon atom contains 6 electrons in orbit around the nucleus, and they have negative (−) charges.

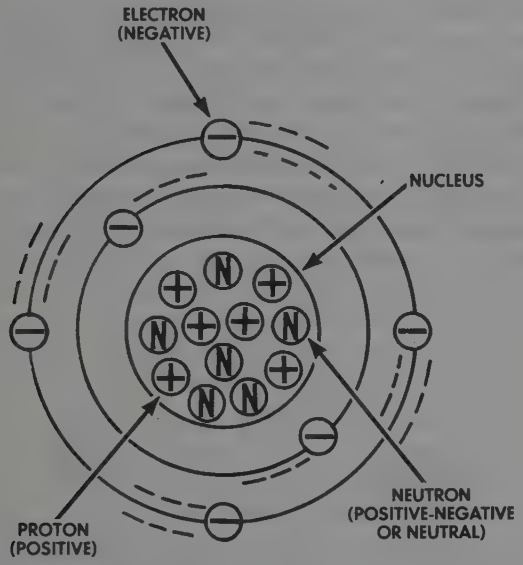


Figure 3-2. This illustration of a carbon atom shows the basic parts of all atoms.

To further clarify the structure and qualities of a carbon atom, Figure 3-3 compares it to our solar system. The *nucleus* (or center) of the carbon atom can be likened to our sun, and the *electrons* can be likened to the planets. Like the planets, the electrons circle in *orbits* around the nucleus at tremendous speed.

NOTE: The structure of different atoms varies in complexity. For example: A hydrogen atom consists of 1 electron orbiting a nucleus that contains 1 proton and no neutrons. A copper atom, on the other hand, has 29 electrons orbiting a nucleus that has 29 protons and 34 neutrons. Regardless of how simple or complex the atom, the nucleus is always positive (+), and the electrons are always negative (−).

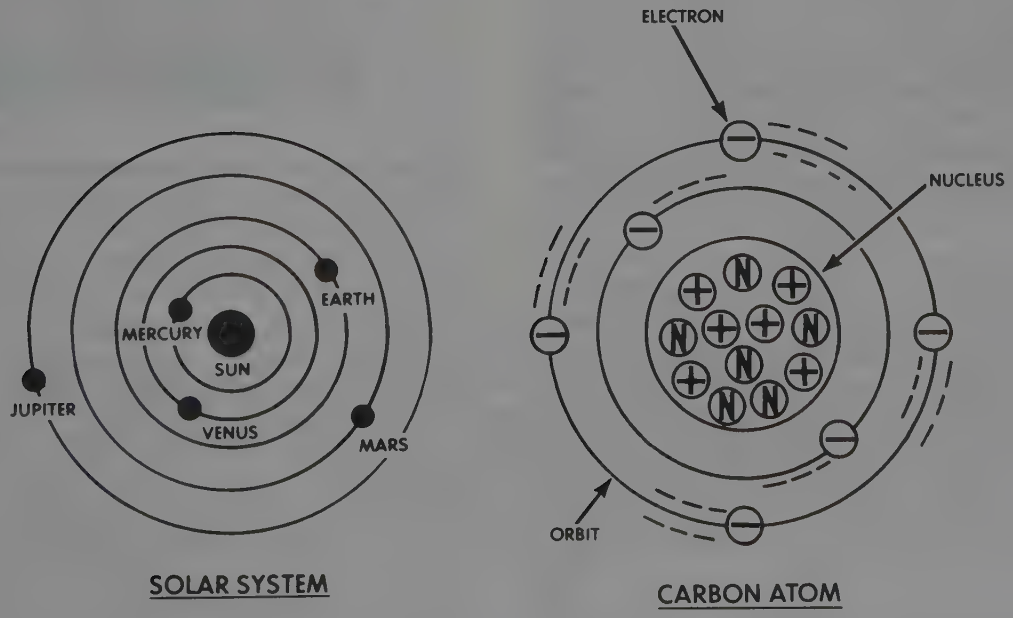


Figure 3-3. A comparison of a carbon atom to our solar system.

Atoms do not normally exist independently, but combine with different atoms in groups called *compounds*. A compound can be broken down into small particles that retain the characteristics of the compound. These small particles are called *molecules*. Molecules give substances or materials their basic characteristics.

In nature, molecules within any given substance or material are not arranged in any particular way. The one exception is the *natural magnet*, which is discussed later in this unit under the heading of "Magnetism."

Electricity

With any atom, the electrons remain in their orbit around the nucleus because of the attraction the negative (—) electrons have for the positive (+) nucleus. The electrons that orbit closest to the nucleus are strongly attached to the nucleus and are called *bound* electrons (Figure 3-4). The electrons that are farthest away from the nucleus can be forced out of their orbits and are called *free* electrons. Free electrons can move from one atom to another atom. When this happens, a form of energy known as **electricity** is created. The movement, or flow, of free electrons from one atom to another atom is called **current**.

For this flow to occur, there must be an imbalance between atoms. Normally, the positive (+) charge of the nucleus balances the negative (—) charge of the electrons. The atom is therefore electrically balanced. However, if a state of imbalance should develop through a loss of electrons, the atom becomes positive (+) in charge. Its natural tendency then is to attract other electrons (—) in order to regain its balance.

Direction of Electron Flow

The terms positive (+) and negative (—) were arbitrarily assigned to electrical charges some 100 years ago when the study of electricity was in its infancy. Before electron flow was completely understood, scientists mistakenly used the term "positive (+) to negative (—)" to explain the direction of current flow. This term is often referred to as the *conventional current flow.*

Scientists now understand that electrons are negatively charged and move toward an area that is missing an electron. The area that is missing an electron is called positive (+). This means that electrons, which are negative (—), always move toward atoms which have a positive (+) charge. Therefore, the flow of current is always from negative (—) to positive (+), as shown in Figure 3-5.

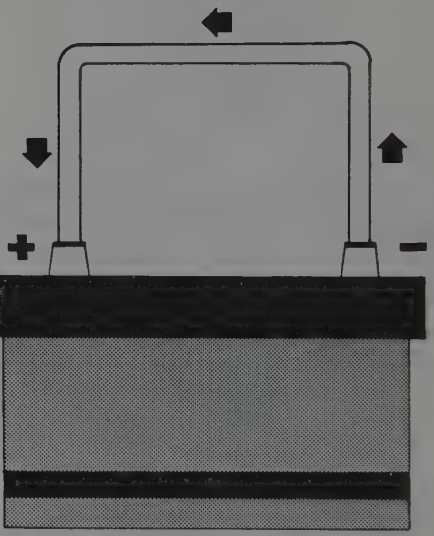


Figure 3-5. Electrons flow from negative (—) to positive (+).

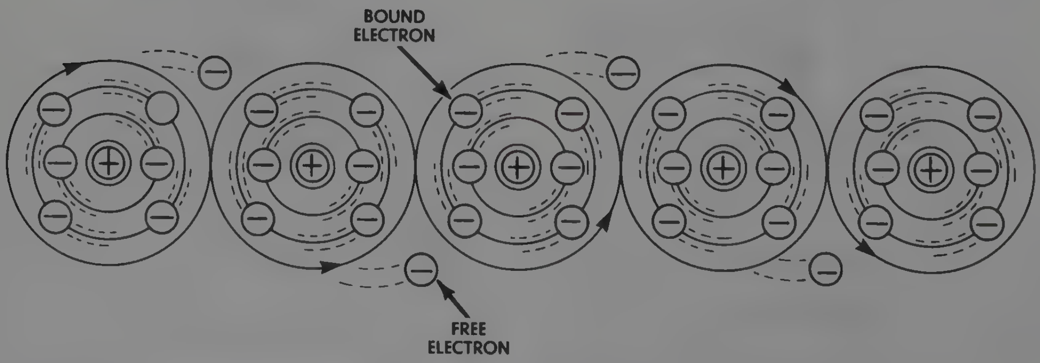


Figure 3-4. Electricity is the movement of free electrons from one atom to another atom.

IMPORTANT: As a student of automotive technology, you should keep in mind that the automotive field adopted conventional current flow [positive (+) to negative (−)] for most of its literature (books and service manuals). Some of the illustrations and explanations in this book reflect this industry norm.

Conductors, Insulators, and Semiconductors

A **conductor** is a material that allows current to flow. The atoms of the material hold their free electrons weakly, so the electrons can be easily forced from their orbits. Also, the atoms are close together, making their free electron orbits overlap. This allows a free electron of one atom to replace one of the electrons in the outer orbit of an adjacent atom. Thus, there can be a continuous movement of electrons from atom to atom with little effort. Copper and aluminum are good conducting materials and are used in many automotive circuits.

An **insulator** is a material that prevents the flow of current, or will not act as a conductor. It is composed of atoms that will not part with any of their free electrons. The bare wires in an automotive electrical circuit are covered with insulator material. This material, referred to as *insulation,* prevents the current from "leaking out" before it gets to its destination. Examples of materials which make good insulators are plastic, Bakelite, and rubber. Additional information on conductors and insulators is given later in this unit under the heading of "Automotive Wire."

A **semiconductor** is a material that has the properties of a conductor and insulator. Elements containing four electrons in their outer orbit are generally classified as semiconductors. Germanium and silicon are two of the several materials that are classed as semiconductors. Under certain conditions, they act as a conductor; and under other conditions, they act as an insulator.

AMPERAGE, VOLTAGE, AND RESISTANCE

Current is the movement of free electrons in sufficient quantity, under pressure, in a conductor. Three terms are commonly used to describe electricity at work: *amperage, voltage,* and *resistance.*

A flow of current through a conductor requires a source of free electrons to supply the demand — just as water in a tank or reservoir is a source for water flow through a pipe. The rate of water flowing through a pipe is measured in gallons per minute. The rate of current flowing in a conductor is measured in amperes, or amps, and is called **amperage**. One ampere equals 6.25×10^{18} electrons passing a given point in a circuit per second.

Just as pressure is necessary to move water in a fire hose, there must be pressure or an electron imbalance to move electrons through a conductor. The amount of pressure pushing the electrons through an electrical circuit is measured in volts and is called **voltage**.

Friction between the walls of a water main (pipe) and the water will cause some resistance to the flow of water. Similarly, some resistance is offered by any material to electron flow through a circuit. Electrical **resistance** is measured in ohms.

OHM'S LAW

The amount of water flowing through a water main will increase if the water pressure is increased. Likewise, the amount of water flowing in the water main will decrease if the resistance offered by the water main increases. In the same way, the amount of current flowing in an electrical circuit will increase if the voltage is increased and will decrease if the resistance of the circuit increases.

The relationship of these electrical factors (voltage, current, and resistance) is summarized by a mathematical equation known as **Ohm's Law.** Ohm's law states that 1 ampere is equal to the amount of current pushed by 1 volt through a resistance of 1 ohm. Mathematically, Ohm's Law is expressed by the following equation: *NOTE: Ohm's Law is usually expressed in the symbols I for current, E for voltage, and R for resistance.*

$$\text{Amperes} = \frac{\text{Volts}}{\text{Ohms}} \quad \text{or} \quad I = \frac{E}{R}$$

This equation is used to calculate the voltage, amperage, or resistance of a circuit. In most cases, a technician can use electrical testing instruments (discussed in Unit 4) to measure these values. There are times, however, when this is not possible. Then, if two of the values are known, the third value may be found by using one of the following equations provided by Ohm's Law:

1. To find current: $I = \frac{E}{R}$
2. To find voltage: $E = IR$
3. To find resistance: $R = \frac{E}{I}$

EXAMPLE: If a circuit has 12 volts and has 2 amperes of current flowing, a technician can use Ohm's Law to determine the resistance as follows:

$$R = \frac{E}{I}$$

$$R = \frac{12}{2}$$

$$R = 6$$

The resistance of the circuit is therefore 6 ohms.

CIRCUITS

A **circuit** is a complete path that allows current to flow. In order for current to flow in a circuit, the path must be unbroken. In fact, the term circuit means circle. Any circuit, no matter how simple or complex, is made up of four basic parts as shown in Figure 3-6. First, there must always be a *source* of electrical pressure, or voltage. In this illustration, the voltage source is a battery. Second, there must always be a *load*. The load in this case is a light bulb. The light bulb will offer resistance and will make use of the current flow. Third, there must always be *conductors* (in this case, wires) to connect the parts of the circuit. Fourth, there must always be a *control device* to open (break) and close (complete) the circuit. In Figure 3-6, the control device is a switch. A circuit, then, has a source, a load, conductors, and a control device.

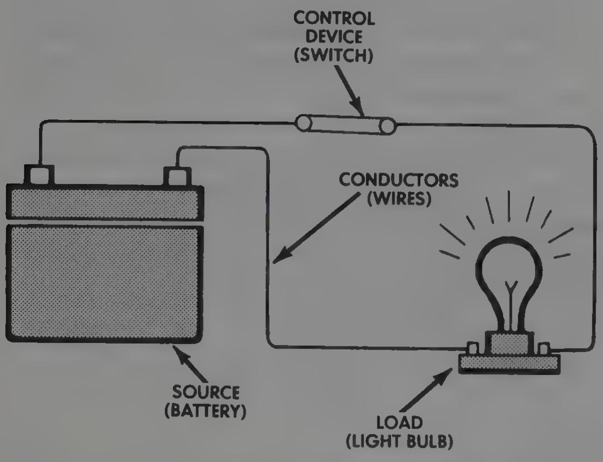


Figure 3-6. The basic parts of any electrical circuit.

Ground Circuit

Not only can current flow through wires, it also can flow through the metal parts of a vehicle such as the frame. Look at the example in Figure 3-7. Instead of a wire from the *light bulb* to the *battery*, we could connect a short wire from the battery post to a *metal frame*. We could then connect a short wire from the light bulb to the same metal frame. Electricity will flow across the closed *switch*, through the light bulb, and continue through the metal frame and short wire to the other battery post. This completes the circuit and the light bulb glows.

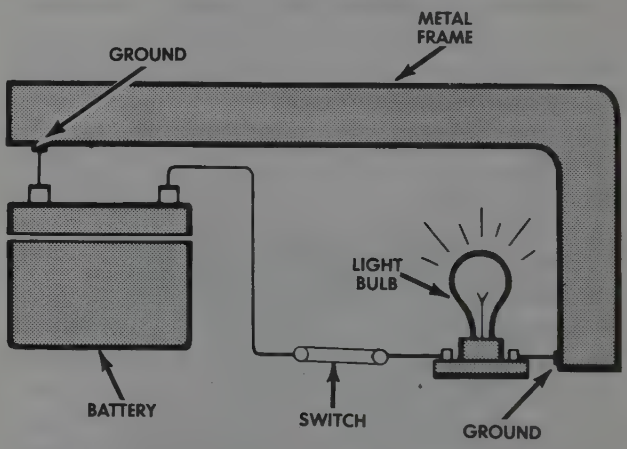


Figure 3-7. Electrical parts can be grounded to complete an electrical circuit.

The point at which the circuit is connected to the metal frame is called the *ground*. Most electrical parts on automobiles have one connection grounded.

Circuit Protectors

Each major circuit in an automobile incorporates a **circuit protector** to protect against an overload or a short (ground). If either of these occurs, enough heat could develop to burn through the wiring and cause an electrical fire. There are three common circuit protectors used in automobiles: *fuses, fusible links,* and *circuit breakers*.

Most of the automobile circuits are protected by *fuses*. One type of fuse is shown in Figure 3-8. It is constructed of a small *glass tube* with *metal caps* on each end. A *metal strip* inside the glass tube allows current to flow. If current flow through the circuit is excessive, the metal strip melts and current flow stops. The glass tube allows a technician to see if the metal strip is severed (melted). If this occurs, the source of difficulty should be located before a new fuse is installed.

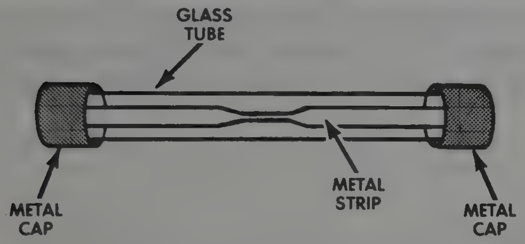


Figure 3-8. A fuse is used to protect a circuit.

Fuses are rated according to the amperage they can handle. The rating, in amps, is marked on the fuse. *SAE 30* means the fuse is rated at 30 amps by the Society of Automotive Engineers. *SFE 30* means it is rated at 30 amps by the Society of Fuse Engineers. **CAUTION: A fuse with the correct rating must always be installed.**

Fuses for various circuits are grouped together and mounted in an accessible *fuse block* or *panel*. Figure 3-9 shows a fuse block that holds another type of fuse, called a *mini-fuse.*

The circuits on some vehicles are protected by *fusible links* (Figure 3-10). The fusible link consists of lengths of specially insulated wire about 4" to 12" long. The wires used are about four sizes smaller in gage than the wires they protect. Some have *push-on terminals* or *connectors* with *protective covers* on both ends, and others are simply sections of wire spliced into the circuit. One or more fusible links may be used and may be located in various places in the wiring (circuits). The fusible links on some automobiles are easily identified by a tag attached to the wire. Others have the same color insulation as the wiring they protect, but the wire gage is smaller. In all cases, the wire is insulated with a special plastic called *Hypalon*, a material which withstands excessive heat. When a short or ground occurs, the wire will melt (like the metal strip in a fuse) before the wiring it protects can be damaged. When this happens, the insulation swells to about twice its normal size. Also, bubbles or blisters form in the insulation.

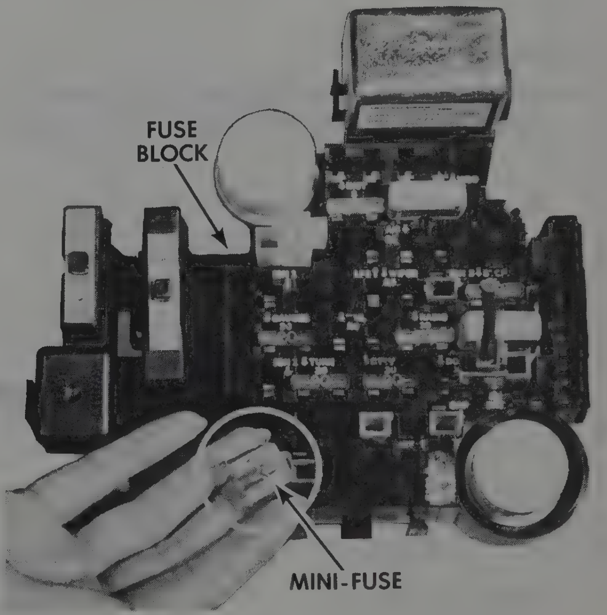


Figure 3-9. A fuse block with a mini-fuse (circled) removed. (Courtesy of Oldsmobile Division, General Motors Corporation)

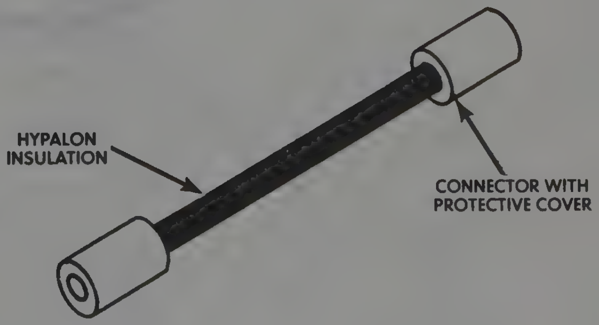


Figure 3-10. Some electrical circuits in vehicles are protected by fusible links.

Another circuit protector, called a *circuit breaker*, is shown in Figure 3-11. It consists of a set of *contact points* and *bimetallic strip*. One of the contact points is attached to the bimetallic strip. Under cold or normal conditions, current flows across the bimetallic strip and contact points, through the circuit. If current becomes excessive, the bimetallic strip gets hot. Because the strip is constructed of two metals with different expansion rates, the heat causes the bimetallic strip to bend. As it bends, it pulls the contact points apart. Current flow is stopped until the metals cool and the contact points close.

Wiring Diagrams

Every automobile manufacturer includes *wiring diagrams* in its service manuals or publishes a book of wiring diagrams. The wiring diagrams show how the various electrical components in the automobile are connected. This helps the tune-up technician troubleshoot electrical problems.

In most wiring diagrams, electrical components are not drawn as they actually look (pictorially), but rather as symbols. Symbols are easier to draw and take up less space than pictures. Common electrical symbols are shown in Figure 3-12. In Figure 3-13, a wiring diagram for a simple circuit is drawn two ways: pictorially and with standard symbols. In each drawing, the circuit represented is identical in function.

Most wiring diagrams have many more electrical components than the simple circuit shown in Figure 3-13. Usually, the wiring diagrams for an automobile fill many pages of a service

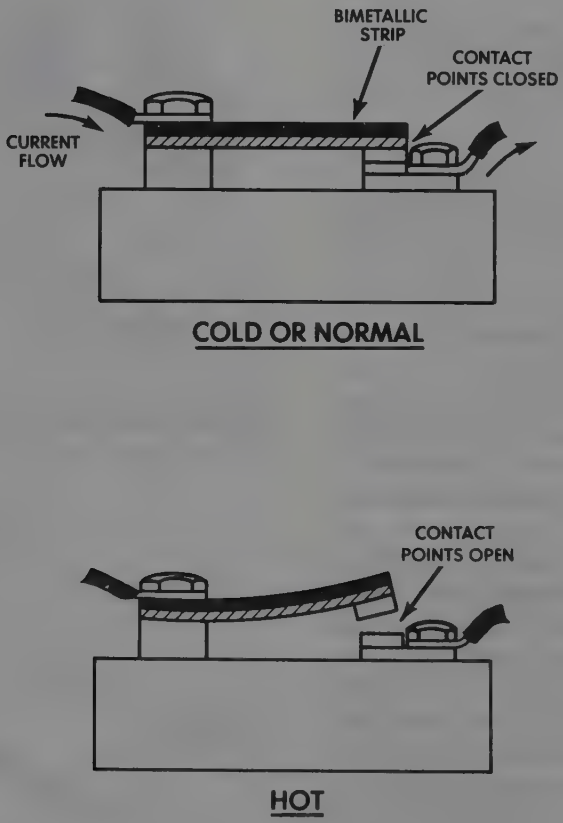


Figure 3-11. Operation of a typical circuit breaker.

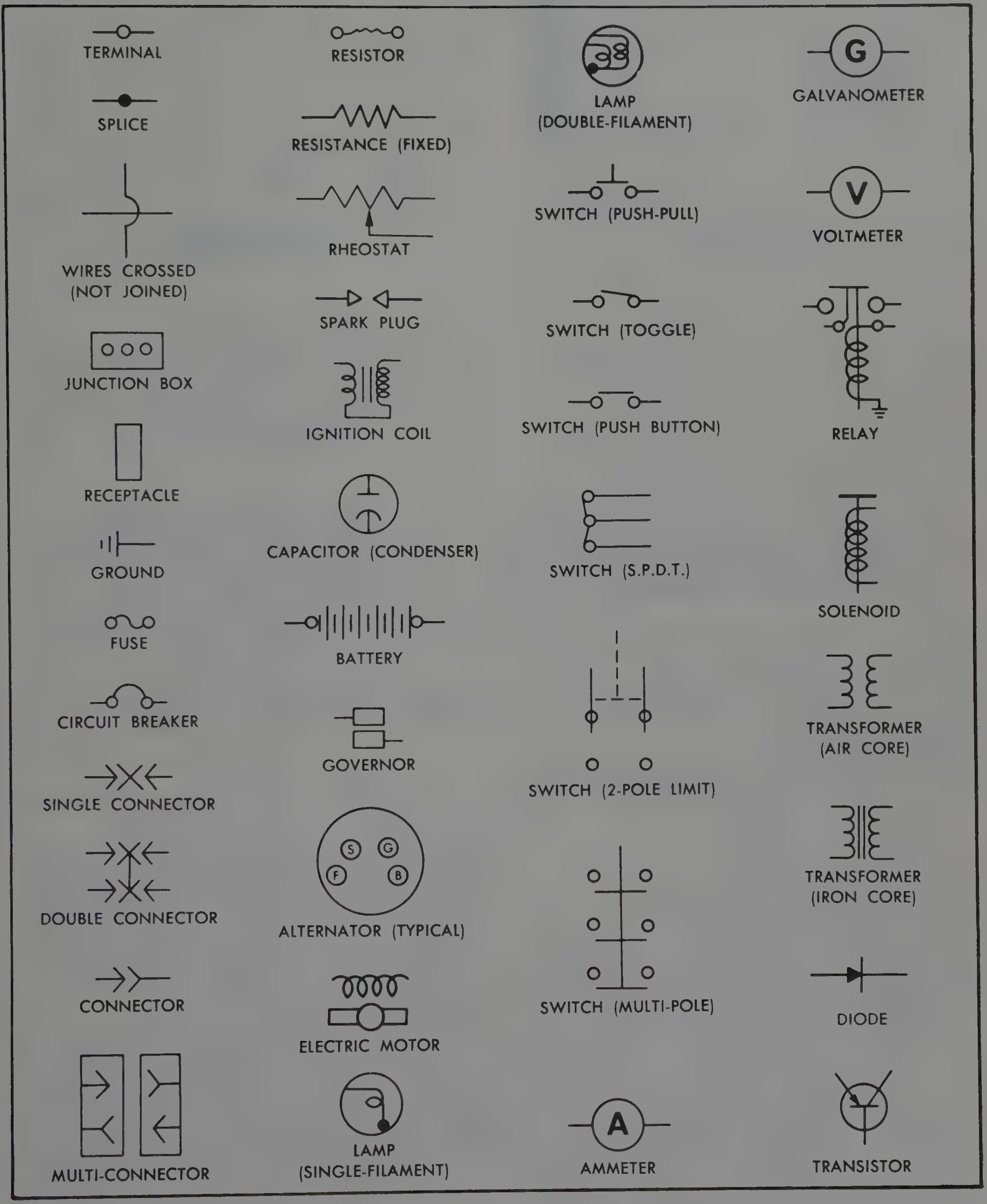

TERMINAL
SPLICE
WIRES CROSSED (NOT JOINED)
JUNCTION BOX
RECEPTACLE
GROUND
FUSE
CIRCUIT BREAKER
SINGLE CONNECTOR
DOUBLE CONNECTOR
CONNECTOR
MULTI-CONNECTOR
RESISTOR
RESISTANCE (FIXED)
RHEOSTAT
SPARK PLUG
IGNITION COIL
CAPACITOR (CONDENSER)
BATTERY
GOVERNOR
S
G
F
B
ALTERNATOR (TYPICAL)
ELECTRIC MOTOR
LAMP (SINGLE-FILAMENT)
LAMP (DOUBLE-FILAMENT)
SWITCH (PUSH-PULL)
SWITCH (TOGGLE)
SWITCH (PUSH BUTTON)
SWITCH (S.P.D.T.)
SWITCH (2-POLE LIMIT)
SWITCH (MULTI-POLE)
A
AMMETER
G
GALVANOMETER
V
VOLTMETER
RELAY
SOLENOID
TRANSFORMER (AIR CORE)
TRANSFORMER (IRON CORE)
DIODE
TRANSISTOR

Figure 3-12. Common electrical symbols. (Courtesy of Ford Motor Company)

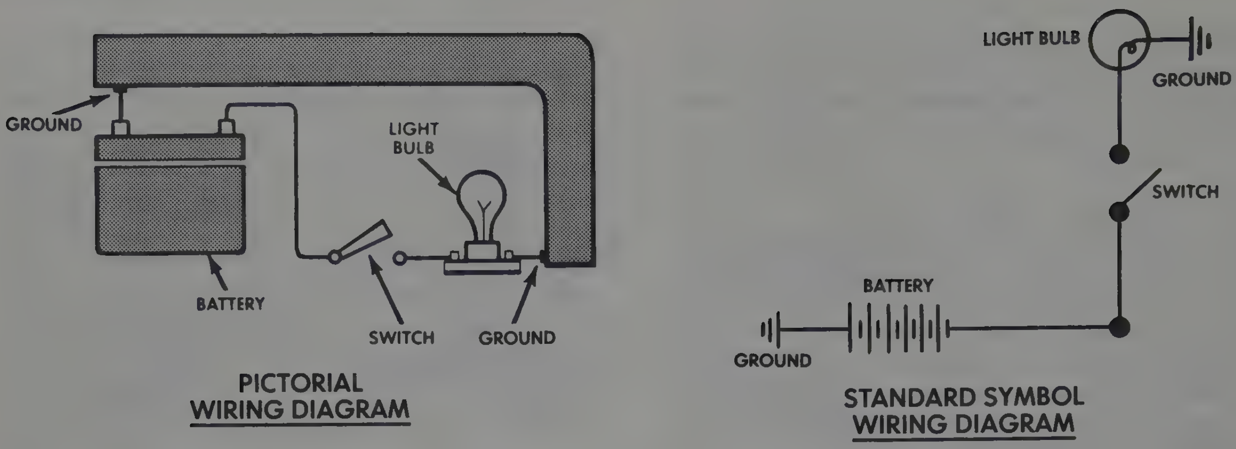

GROUND
LIGHT BULB
BATTERY
SWITCH
GROUND
PICTORIAL WIRING DIAGRAM
LIGHT BULB
GROUND
SWITCH
BATTERY
GROUND
STANDARD SYMBOL WIRING DIAGRAM

Figure 3-13. A simple circuit drawn two ways.

manual. A wiring diagram for the engine compartment of a vehicle is shown in Figure 3-14.

In order to help the technician trace the more complex circuits, the wires in an automobile are different colors. The wiring diagrams have a *color code*, as shown in the lower right corner of Figure 3-14, that corresponds to the wires in the automobile. Unless the wiring diagram is printed in the same colors as the wires, the color code is necessary to tell the technician exactly what color each wire will be in the automobile.

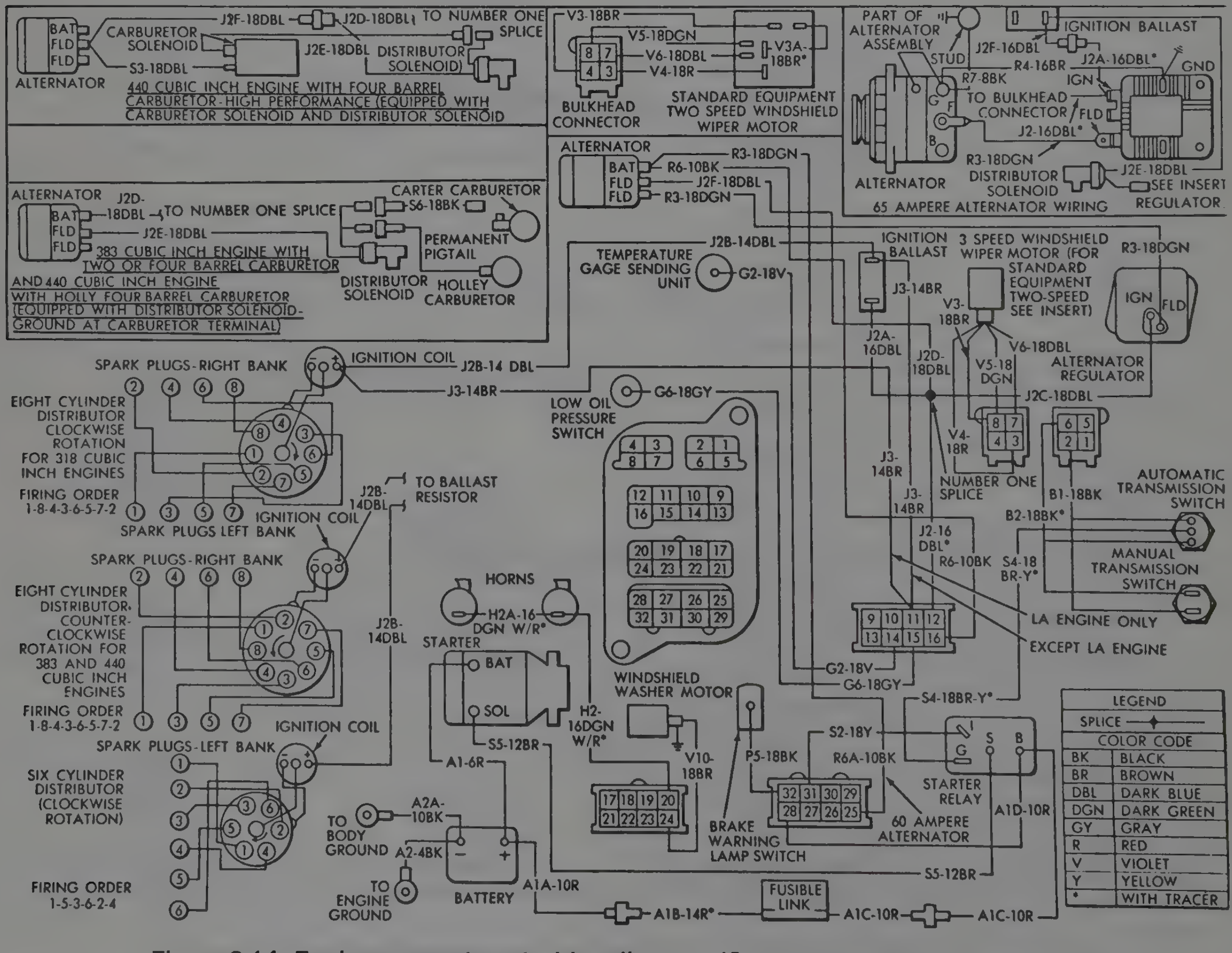

ALTERNATOR
BAT
FLD
FLD
CARBURETOR SOLENOID
J2F-18DBL
J2D-18DBL
TO NUMBER ONE SPLICE
J2E-18DBL
DISTRIBUTOR SOLENOID
S3-18DBL
440 CUBIC INCH ENGINE WITH FOUR BARREL CARBURETOR-HIGH PERFORMANCE (EQUIPPED WITH CARBURETOR SOLENOID AND DISTRIBUTOR SOLENOID
V3-18BR
V5-18DGN
V6-18DBL
V4-18R
V3A-18BR*
BULKHEAD CONNECTOR
STANDARD EQUIPMENT TWO SPEED WINDSHIELD WIPER MOTOR
PART OF ALTERNATOR ASSEMBLY
STUD
J2F-16DBL
IGNITION BALLAST
R4-16BR
J2A-16DBL*
GND
R7-8BK
IGN
TO BULKHEAD CONNECTOR
FLD
J2-16DBL*
R3-18DGN
DISTRIBUTOR SOLENOID
J2E-18DBL
SEE INSERT REGULATOR
ALTERNATOR
65 AMPERE ALTERNATOR WIRING
ALTERNATOR
R3-18DGN
R6-10BK
J2F-18DBL
R3-18DGN
J2D-18DBL
TO NUMBER ONE SPLICE
J2E-18DBL
CARTER CARBURETOR
S6-18BK
PERMANENT PIGTAIL
383 CUBIC INCH ENGINE WITH TWO OR FOUR BARREL CARBURETOR AND 440 CUBIC INCH ENGINE WITH HOLLY FOUR BARREL CARBURETOR (EQUIPPED WITH DISTRIBUTOR SOLENOID-GROUND AT CARBURETOR TERMINAL)
DISTRIBUTOR SOLENOID
HOLLEY CARBURETOR
TEMPERATURE GAGE SENDING UNIT
G2-18V
J2B-14DBL
IGNITION BALLAST
J3-14BR
3 SPEED WINDSHIELD WIPER MOTOR (FOR STANDARD EQUIPMENT TWO-SPEED SEE INSERT)
V3-18BR
R3-18DGN
IGN
FLD
V6-18DBL
ALTERNATOR REGULATOR
J2A-16DBL
J2D-18DBL
V5-18DGN
J2C-18DBL
SPARK PLUGS-RIGHT BANK
IGNITION COIL
J2B-14 DBL
J3-14BR
EIGHT CYLINDER DISTRIBUTOR CLOCKWISE ROTATION FOR 318 CUBIC INCH ENGINES
FIRING ORDER 1-8-4-3-6-5-7-2
SPARK PLUGS LEFT BANK
IGNITION COIL
J2B-14DBL
TO BALLAST RESISTOR
LOW OIL PRESSURE SWITCH
G6-18GY
V4-18R
J3-14BR
NUMBER ONE SPLICE
J3-14BR
J2-16 DBL*
R6-10BK
S4-18 BR-Y*
B1-18BK
B2-18BK*
AUTOMATIC TRANSMISSION SWITCH
MANUAL TRANSMISSION SWITCH
LA ENGINE ONLY
EXCEPT LA ENGINE
SPARK PLUGS-RIGHT BANK
EIGHT CYLINDER DISTRIBUTOR, COUNTER-CLOCKWISE ROTATION FOR 383 AND 440 CUBIC INCH ENGINES
FIRING ORDER 1-8-4-3-6-5-7-2
IGNITION COIL
SPARK PLUGS-LEFT BANK
J2B-14DBL
HORNS
H2A-16-DGN W/R*
STARTER
BAT
SOL
H2-16DGN W/R*
S5-12BR
A1-6R
WINDSHIELD WASHER MOTOR
V10-18BR
G2-18V
G6-18GY
S4-18BR-Y*
S2-18Y
P5-18BK
R6A-10BK
STARTER RELAY
G
S
B
A1D-10R
60 AMPERE ALTERNATOR
BRAKE WARNING LAMP SWITCH
SIX CYLINDER DISTRIBUTOR (CLOCKWISE ROTATION)
FIRING ORDER 1-5-3-6-2-4
TO BODY GROUND
A2A-10BK
A2-4BK
TO ENGINE GROUND
BATTERY
A1A-10R
A1B-14R*
FUSIBLE LINK
A1C-10R
A1C-10R
S5-12BR
LEGEND
SPLICE
COLOR CODE
BK BLACK
BR BROWN
DBL DARK BLUE
DGN DARK GREEN
GY GRAY
R RED
V VIOLET
Y YELLOW
* WITH TRACER

Figure 3-14. Engine compartment wiring diagram. (Courtesy of Chrysler Corporation)

MAGNETISM

As mentioned in this unit under the heading of "Atoms," molecules within any given substance or material are not arranged in any particular way (Figure 3-15, top). The exception to this is the natural magnet. In a natural magnet, all the molecules are lined up and "face" in the same direction (Figure 3-15, bottom). When the molecules of a metal (soft iron or steel) are lined up, a force is developed called **magnetism**. Atoms have magnetic fields. If all those magnetic fields are lined up, the strength of the magnetism is increased.

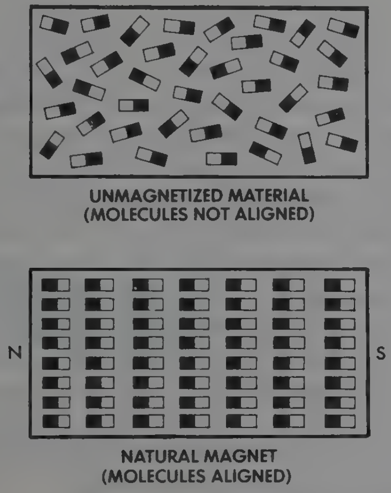


Figure 3-15. A comparison of the molecule arrangement of unmagnetized material to that of a natural magnet. (Courtesy of Delco Remy, Division of General Motors Corporation)

Temporary and Permanent Magnets

Soft iron and steel, like all other matter, are made up of molecules. Each molecule is a small magnet in itself. However, the molecules in an unmagnetized bar of soft iron or steel are normally completely disarranged.

When soft iron is magnetized, the molecules are parallel to the force of magnetic attraction. When removed from the magnetic field, the molecules in the soft iron tend to become disarranged again. However, when steel is magnetized, the molecules remain lined up. Steel continues to be a magnet even when removed from the magnetic field. Thus, steel is used to make permanent magnets, while soft iron is used to make temporary magnets.

Magnetic Fields

If we were to sprinkle some iron filings on a piece of paper and lay a bar magnet in the filings, we would find that almost all of the iron filings would attach themselves at or near the ends of the magnet. This tells us that the magnetic force is strongest at or near the ends of the magnet. These areas are called the *magnetic poles*. One end of the magnet always points north and is called north-seeking or the *N-pole* (north pole). The other end is called south-seeking or the *S-pole* (south pole).

If we were to place a bar magnet under a thin sheet of smooth cardboard, sprinkle iron filings evenly on the cardboard, and tap the edges of the cardboard with a pencil, we would see a pattern of filings develop. This pattern shows that a magnetic field surrounds the magnet. The magnetic field can be described as the magnet's *lines of force* (Figure 3-16).

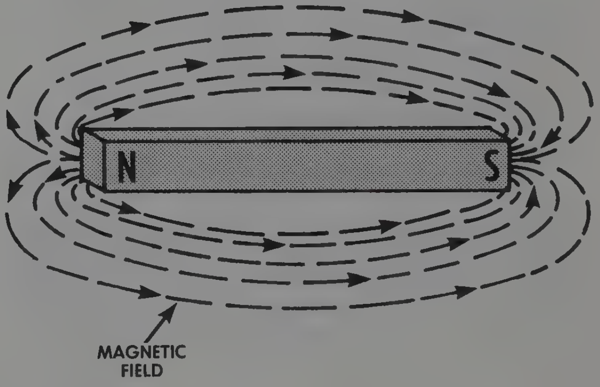


Figure 3-16. A magnetic field (lines of force) surrounds a magnet. (Courtesy of Delco Remy, Division of General Motors Corporation)

There is no insulator for magnetic lines of force. They will pass through any material. However, some materials let a magnetic field through more easily than others. Thus, by choosing the right material, we can concentrate magnetic lines of force where needed or weaken them where they are undesirable.

Magnetism and Electricity

A conductor carrying an electric current also produces a magnetic field, called an *electromagnetic field.* It too has lines of force and direction (north and south poles). When electric current is passed through a conductor that is formed into a loop, a weak magnet with a north and south pole is created (Figure 3-17). If several loops are formed with the conductor, it becomes a *coil*, and a stronger magnetic field is created. The lines of force around the coil form a north and south pole just as a bar magnet does. The strength of the magnetic field around the coil may be increased by: (1) increasing the number of coils or turns, (2) increasing the amount of current in the coils, or (3) increasing both the number of turns and the amount of current.

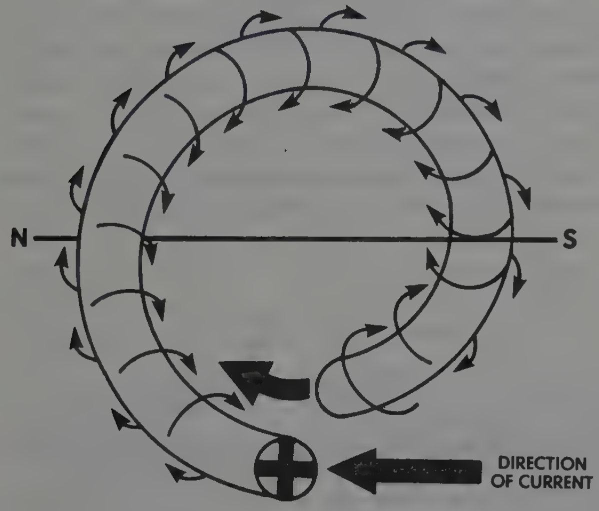


Figure 3-17. A magnetic field surrounds a current-carrying conductor. (Courtesy of Delco Remy, Division of General Motors Corporation)

Another means of increasing the magnetic field surrounding a coil is to insert a soft iron bar, called a *core*, inside the coil. Since the soft iron allows the magnetic field to pass through it with less resistance than air, the strength of the magnetic field is greatly increased. The magnet formed by a coil of wire around a soft iron core is called an *electromagnet.*

Induction

Induction is the transfer of energy from one object to another without the objects being in physical contact with each other. Induction is generally caused through the magnetic fields surrounding conductors and magnets.

As mentioned, a magnetic field surrounds a current-carrying coil. If a current-carrying coil is placed near another coil without current, the current-carrying coil will influence the other coil as shown in Figure 3-18. In this illustration, when the switch is opened, the magnetic field around the current-carrying coil collapses. This collapsing magnetic field causes current to flow in the other coil, and the light bulb lights for a fraction of a second. This kind of induction is used in automotive ignition coils.

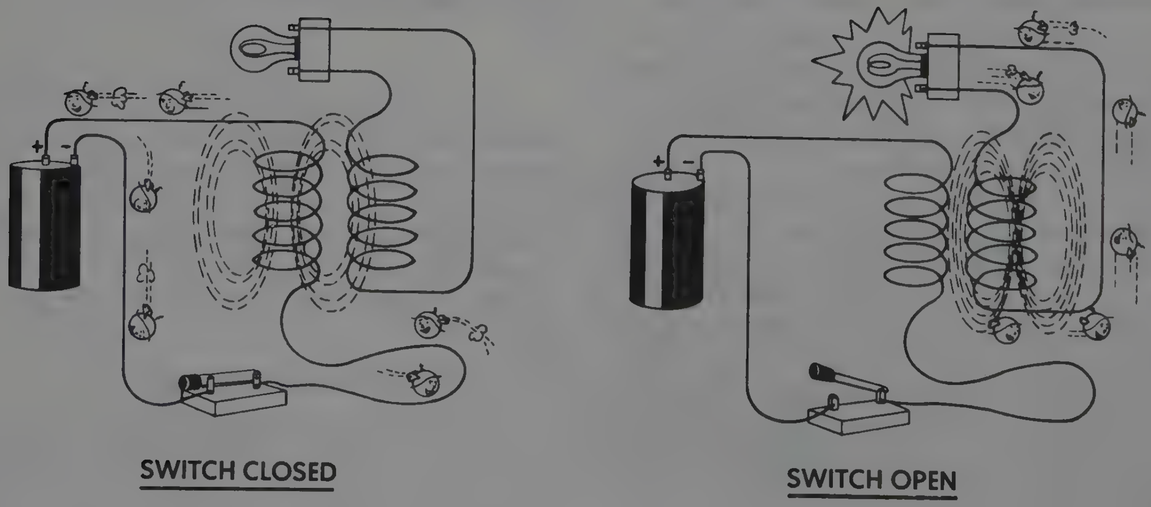


Figure 3-18. A collapsing magnetic field causes current to flow. (Courtesy of Ford Motor Company)

AUTOMOTIVE WIRE

Most **automotive wire** (Figure 3-19) consists of a conductor covered with an insulation. The *center core* is made from a conductor, usually copper, and is *single-strand* or *solid* wire or *multi-strand* wire. Multi-strand wire is more flexible than solid wire and for this reason, it is used in most automotive applications.

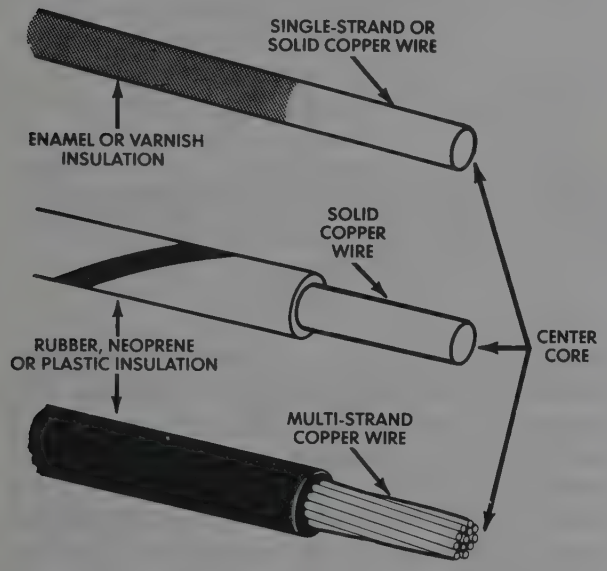

SINGLE-STRAND OR SOLID COPPER WIRE
ENAMEL OR VARNISH INSULATION
SOLID COPPER WIRE
CENTER CORE
RUBBER, NEOPRENE OR PLASTIC INSULATION
MULTI-STRAND COPPER WIRE

Figure 3-19. Basic types of automotive wire.

The copper conductor is insulated to prevent grounds or shorts. The insulation must have a very high resistance, provide a good deal of strength, and age without becoming brittle. For very thin wire used on the inside of electrical equipment, the only insulation used may be a coat of enamel or varnish. This wire may look like naked copper wire, but the enamel or varnish provides the necessary insulation. Enamel or varnish insulated wire is usually called *magnet wire* because it is often used around magnets where space is at a premium inside motors and generators. Wire used on the outside of electrical components is usually insulated with rubber, neoprene, or plastic.

Wires for automotive use can be classified into four general categories: *battery cables*, *ignition cables*, *general wiring*, and *printed circuits*. The battery is connected to the electrical system with very large-diameter wires, called *battery cables*, which have terminals soldered on each end (Figure 3-20). They connect the battery to the starter motor and ground. The starter motor requires a large amount of current. Large-diameter battery cables provide the capacity for that amount of current. The ground connection at the battery uses an insulated battery cable or a braided copper ground strap. Since battery cables are subjected to corrosive battery gases, corrosion eventually increases the resistance in the circuit and eventually destroys the cable and terminal. Replacement battery cables must be carefully selected to match the requirements of the electrical system. A battery cable that has too large or too small a center core will not function properly.

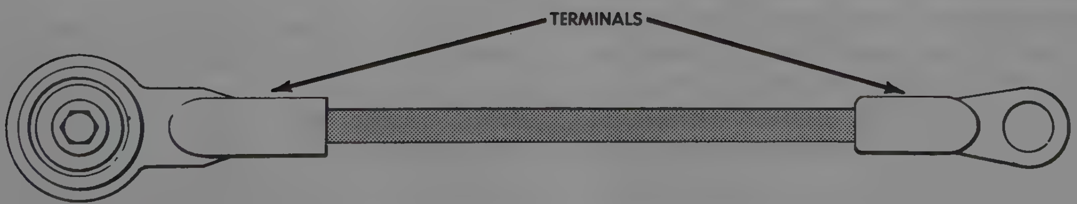


Figure 3-20. Battery cables are large-diameter insulated wires with terminals soldered to each end. (Courtesy of Belden Corporation)

Ignition cables, or spark plug cables, (Figure 3-21) have a special electrical function. They must route high-voltage electrical current to each of the engine's spark plugs. The ignition cables must be able to handle 30,000 V or more. These cables are discussed in detail in Unit 12.

Most of the wiring in an automobile falls into the category of general wiring. The wire used is a multi-strand, copper wire, covered with a plastic insulation that is color-coded. The wires are grouped together and routed to various locations on the vehicle through plastic shields called *wiring harnesses*. The wiring harness protects the wires from possible damage where they pass near metal edges.

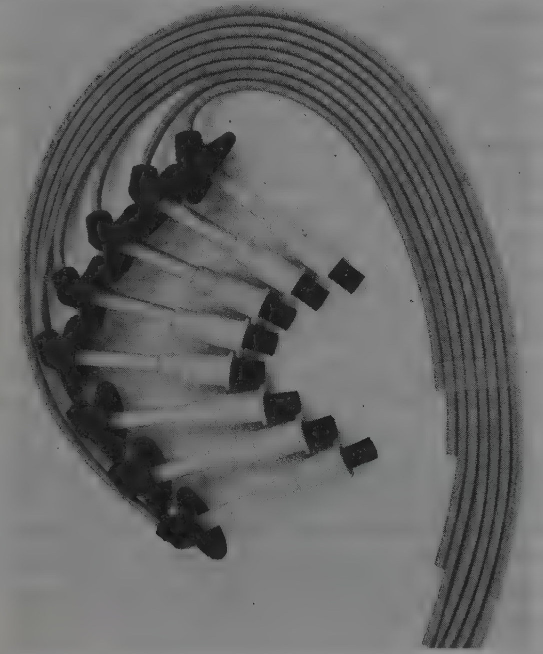


Figure 3-21. Ignition cables or spark plug cables carry high-voltage electrical current for ignition.

The use of wires has been diminishing in electronic equipment. Instead, printed wiring, called the *printed circuit* is used (Figure 3-22). Electronic components are bonded to a flat *insulating plate* (usually referred to as a *PC board*). Instead of wires, conducting paths (circuits) are printed on the insulating plate, much as words are printed on a page. Printed circuits have the advantage of compactness and good connections. They are used in transistorized voltage regulators, transistorized ignition systems, and in many automotive instrument panels.

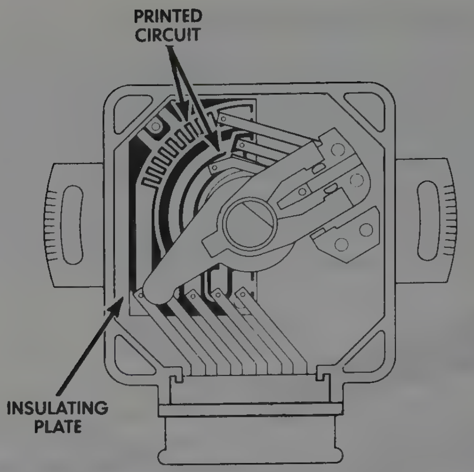


Figure 3-22. Current can flow through a circuit printed on an electrical component. (Courtesy of Robert Bosch Sales Corporation, Service Department)

Wire Size

Wire size is based upon a system known as the *American Wire Gage (AWG)* or *Brown and Sharpe (B & S) Gage*. The gage numbers specify the size of the conductor center core in terms of its *diameter* and *circular mil area*, which is a cross-sectional area. A circular mil, abbreviated *cmil*, is a standard unit of measure for the cross-sectional area of the center core. A mil is one-thousandth of an inch (.001). A typical wire table is shown in Figure 3-23. Column 1 shows the AWG numbers from 0000 to 36. Column 2 shows the center core diameter in inches.

NOTE: The diameter of the wire is always specified by the diameter of the center core, not by the outside diameter of the insulation.

A comparison of Columns 1 and 2 shows that as the gage numbers increase, the diameter of the center core decreases. This fact is often misunderstood. The circular mil area doubles for approximately every three gage sizes. For example, Column 3 shows that a No. 10 wire has approximately twice the area of a No. 13 wire.

The current-carrying ability of a wire is determined by its cross-sectional area (circular mil area). The greater the cross-sectional area is, the more current can flow through the wire. The smaller the cross-sectional area is, the more resistance exists and the less current can flow. The wire size of a circuit is carefully determined by automotive electrical engineers to meet specific requirements. For example, large battery cables are often No. 1 or No. 2 gage because a larger flow of current is needed. On the other hand, a No. 16 gage wire is often used with a headlight because less current is needed. Therefore, when a wire is replaced, it must be the same size as the one it is replacing.

New wire is sold in spools that are clearly identified by AWG size. Wire size in various circuits on the automobile are often identified on the wiring diagrams. Two procedures can be used to discover the size of an unidentified wire. First, a wire gage is available which has a series of graduated holes. Numbers are printed on the wire gage to correspond with the hole sizes. The center core of the wire to be identified is inserted into the various holes to determine the closest fit. If a wire gage is not available a second procedure can be used. The diameter of the center core can be measured with an outside micrometer and then be matched to a wire table to determine the size of the wire.

WIRE TABLE		
AMERICAN WIRE GAGE NO.	CENTER CORE DIAMETER (INCHES)	CENTER CORE CIRCULAR MIL AREA
0000	.4600	211600
000	.4096	167772
00	.3648	133079
0	.3249	105560
1	.2893	83695
2	.2576	66358
3	.2294	52624
4	.2043	41739
5	.1819	33088
6	.1620	26244
7	.1443	20823
8	.1285	16512
9	.1144	13087
10	.1019	10384
11	.0907	8227
12	.0808	6529
13	.0720	5184
14	.0641	4109
15	.0571	3260
16	.0508	2581
17	.0453	2052
18	.0403	1624
19	.0359	1289
20	.0320	1024
21	.0285	812.3
22	.0253	640.1
23	.0226	510.8
24	.0201	404.0
25	.0179	320.4
26	.0159	252.8
27	.0142	201.7
28	.0126	158.8
29	.0113	127.7
30	.0100	100.0
31	.0089	79.21
32	.0079	62.41
33	.0070	49.00
34	.0063	39.69
35	.0056	31.36
36	.0050	25.00

Figure 3-23. A typical wire table.

Wire Resistance

The cross-sectional area of a wire is related to the electrical resistance the wire offers. The smaller its cross-sectional area, the higher the resistance the wire offers (Figure 3-24).

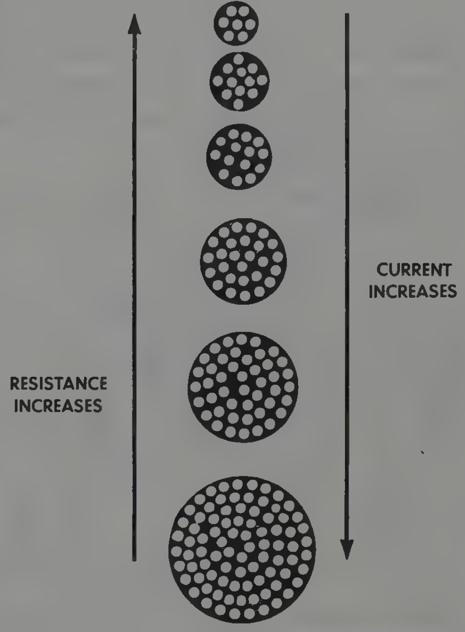


Figure 3-24. The core area determines the resistance of a wire.

Other factors also help determine the resistance a wire offers, and a tune-up technician should be aware of them. One factor is the length of the wire. The longer the wire, the more resistance it offers. When replacing a wire, a careful match must be made, not only of size, but of length. Another factor is the material used as a conductor. Copper, aluminum, and silver offer little resistance. However, in some cases, resistance is desirable. For example, high resistance develops the heat that is needed in a heating element. Many common household appliances such as irons, toasters, and percolators are heated by electricity. In automotive use, electric carburetor chokes are heated by electrical resistance. A wire with a higher resistance than copper must be used as the heating element in all these devices. Usually, a high-resistance wire made from nickel and chromium, called *nichrome*, is used.

Wire Terminal Connectors

When a replacement wire is installed in a circuit, terminal connectors must be installed on the ends of the wire. Wire terminals are sold in various sizes and shapes (Figure 3-25). The correct wire terminal connector must be used so that it will connect properly to the terminal on the component. It must also match the gage size of the wire. Wire terminal connectors may be installed by crimping or squeezing the terminal on the wire or by soldering. Soldering provides the best connection.

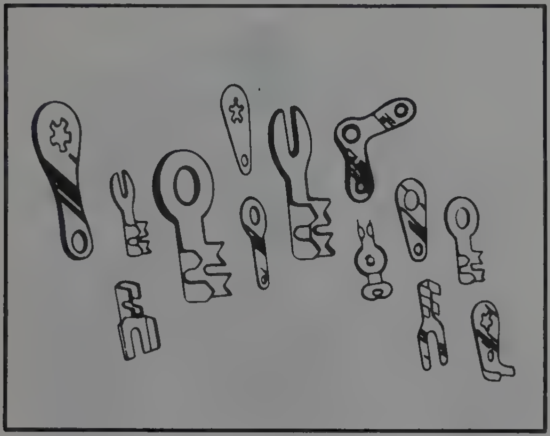


Figure 3-25. Wire terminal connectors are available in various shapes and sizes.

Before the terminal wire connector can be attached, the protective insulation must be stripped away (Figure 3-26). Various types of stripping knives and pliers are available for this purpose. Just enough of the insulation must be removed to attach the terminal. Magnet wire can be soldered only after the enamel or varnish insulation is removed.

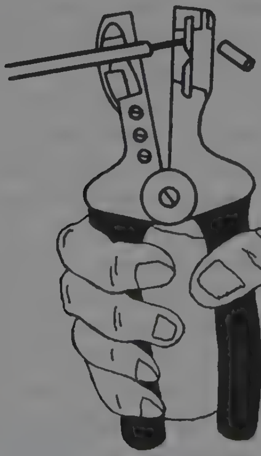


Figure 3-26. Wire strippers are used to remove insulation from wire.

Original equipment wiring often has connectors made in two parts which allow the wires to be disconnected for service. The connectors shown in Figure 3-27 are often called *push-pull connectors* because they are pushed together to connect and pulled apart to disconnect.

Soldering Wire Terminal Connectors. When the wire terminal connector is attached and crimped, it should be soldered. A soldering gun or soldering iron is used to heat the wire terminal connector and the wire center core. When sufficient heat is developed, solder is melted onto the connection. As soon as the area is wet with solder, the heat source is removed and the joint held until the solder cools and turns solid.

KEY TERMS

Amperage: The rate of current flowing in a conductor.

Atom: The smallest particle into which an element can be divided and still retain its characteristics as an element.

Automotive wire: A conductor covered with insulation and used to provide a path for current flow.

Circuit: A complete path that will allow electrical current to flow.

Circuit protector: Fuses, fusible links, or circuit breakers used to protect against an overload or short or ground.

Conductor: A material that allows current to flow.

Current: The flow of free electrons.

Electricity: A form of energy.

Induction: The transfer of energy from one object to another without the objects being in physical contact with each other.

Insulator: A material that prevents the flow of current, or will not act as a conductor.

Magnetism: A force developed when the molecules of a metal are lined up and face in the same direction.

Matter: Defined by scientists as "that of which any physical object is composed".

Ohm's law: The relationship of electrical factors (voltage, current, and resistance) which states that 1 ampere is equal to the amount of current pushed by 1 volt through a resistance of 1 ohm.

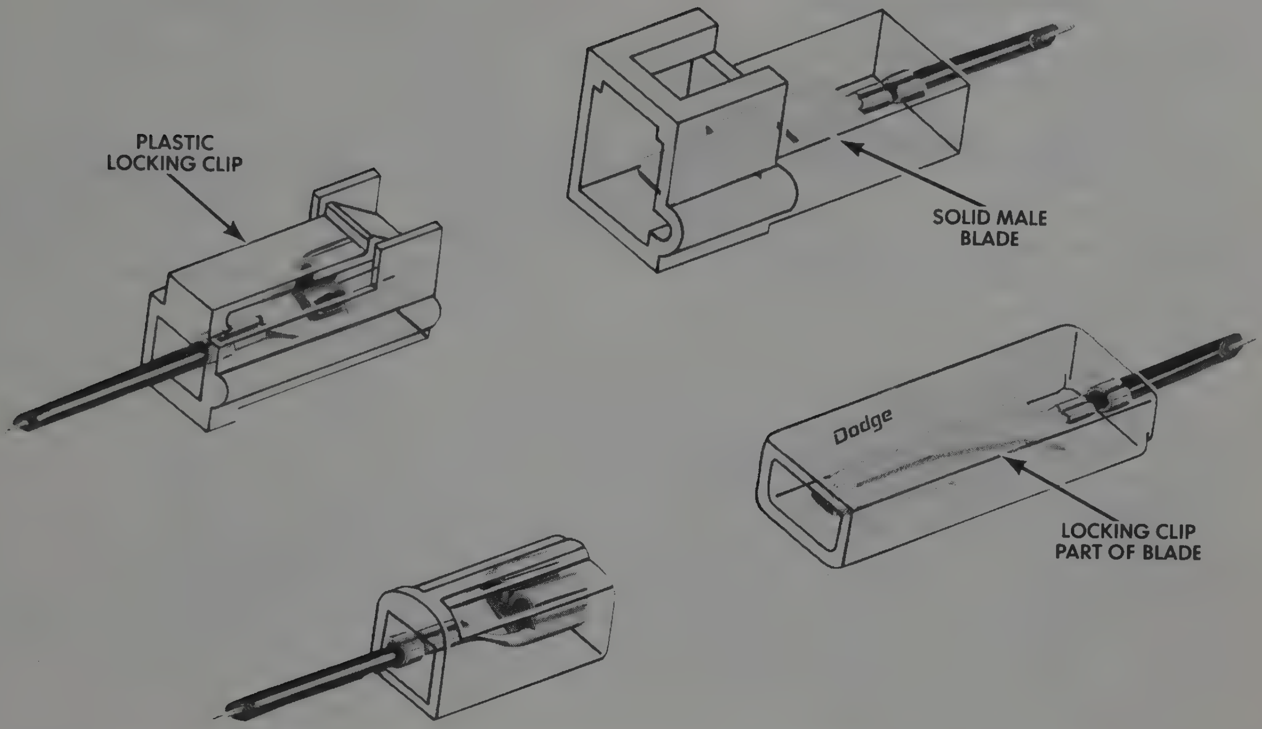


Figure 3-27. Two examples of push-pull connectors. (Courtesy of Chrysler Corporation)

Resistance: An electrical term used to describe the resistance to current flow in a circuit.

Semiconductor: A material that has the properties of a conductor and insulator.

Voltage: An electrical term used to describe the amount of electrical pressure in a circuit.

Wire size: The size of a wire based upon the diameter and circular mil area of its center core.

SELF-CHECK

1. What are the three parts of an atom?
2. Explain how electrons can flow from one atom to another atom?
3. What is the difference between a conductor, insulator, and semiconductor?
4. What is the relationship between voltage, amperage, and resistance?
5. What is an electrical circuit?
6. What is a ground or grounded circuit?
7. What is the purpose of a wiring diagram?
8. What is the difference between a temporary and a permanent magnet?
9. What is the relationship between magnetism and electricity?
10. Explain how induction can be used to transfer energy.
11. What are the two types of wire that can be used for the center core of automotive wire?
12. List the four general categories of automotive wire.
13. Explain how automotive wire size is determined.
14. What is the relationship between wire size and electrical resistance?
15. List and describe the three common circuit protectors used in automobiles.

DISCUSSION TOPICS AND ACTIVITIES

1. Use a set of magnets and iron filings to observe magnetic fields.
2. Construct a basic circuit with a battery, light bulb, switch, and wire.

CERTIFICATION PRACTICE

1. An atom is composed of:
   - A. A nucleus containing protons and neutrons
   - B. A number of orbiting electrons
   - C. Both A and B
   - D. Neither A nor B
2. The movement of free electrons from one atom to another atom is known as:
   - A. Electron flow
   - B. Atomic fission
   - C. Nuclear fission
   - D. Electron bounce
3. The force or potential that pushes electrons is called:
   - A. Resistance
   - B. Current
   - C. Voltage
   - D. Reluctance
4. The flow of electrons is called:
   - A. Resistance
   - B. Current
   - C. Voltage
   - D. Reluctance
5. The opposition to the flow of electrons is called:
   - A. Resistance
   - B. Current
   - C. Voltage
   - D. Reluctance

ANSWERS

1: C, 2: A, 3: C, 4: B, 5: A

Unit 4 TUNE-UP TOOLS AND EQUIPMENT

The instruments used to perform a tune-up vary from small, hand-held, portable tools to large, permanently mounted pieces of equipment. The type of tools and equipment available determines, to a large extent, the tune-up procedure that will be used. For example, with some of the more sophisticated testing equipment, the technician simply connects the equipment to the vehicle. The equipment then automatically makes a programmed series of engine tests and records the results on a screen or on a printer. With other types of testing equipment, the technician must manually perform the testing and compare the findings to specifications. Common types of electrical and mechanical instruments used for a tune-up are described in this unit.

DEVELOPING JOB COMPETENCIES

When you finish reading and studying this unit, you should be able to:

- Explain how to read an electrical wiring diagram.
- Explain how to use an ammeter, voltmeter, and ohmmeter.
- Explain how to use an oscilloscope test an ignition system.
- Explain how to use a dynamometer.
- Explain how to use an exhaust analyzer to sample exhaust gases.
- Explain how to use a computerized tester.
- List and describe the common mechanical testing instruments and tools.

ELECTRICAL INSTRUMENTS

Electrical system troubleshooting requires that the tune-up technician know how to use electrical testing instruments properly. These special instruments provide a quick and accurate method for testing electrical systems and components. Basic rules for their operation are:

1. All electrical measuring instruments are fragile. If dropped, they must be checked for accuracy and proper operation.

2. When using electrical testing equipment, the technician must be certain that the instrument is set to the correct scale. Most electrical instruments have a scale selector switch that allows technicians to measure different amounts of current, voltage, or resistance.

3. If, when the instrument is connected, its pointer jumps all the way over to the right, the scale is not set high enough. The instrument is in danger of overloading. To be sure of the correct scale, it is good practice to begin with the highest scale on a meter and then select a lower scale if necessary.

Voltmeter

Voltage is electrical pressure in a circuit. The instrument used to measure voltage is called a **voltmeter**. The unit of measurement for voltage is the *volt* (V). An inside view of a voltmeter is shown in Figure 4-1. The voltmeter uses a *permanent horseshoe magnet* and a *movable coil*. Current flowing through the movable coil reacts to the magnetic field of the permanent horseshoe magnet, causing the movable coil to turn. The amount the movable coil turns is determined by the amount of current flowing through the movable coil. This is in turn determined by the amount of voltage in the circuit being measured. The *pointer*, attached to the movable coil, swings across a *scale*, or range, divided into units of measure (volts). The pointer indicates directly on the scale the voltage of the circuit. The pointer returns to zero when the meter is disconnected.

The movable coil must be sensitive enough to measure small voltages. For this reason, voltmeters are built with a *resistor* in series with the movable coil to limit current to a safe value. The meter is calibrated, taking the resistor into account, to measure true voltage. Some voltmeters have a scale selector switch. This allows resistors of different values to be inserted in series with the movable coil for measuring different amounts of voltage.

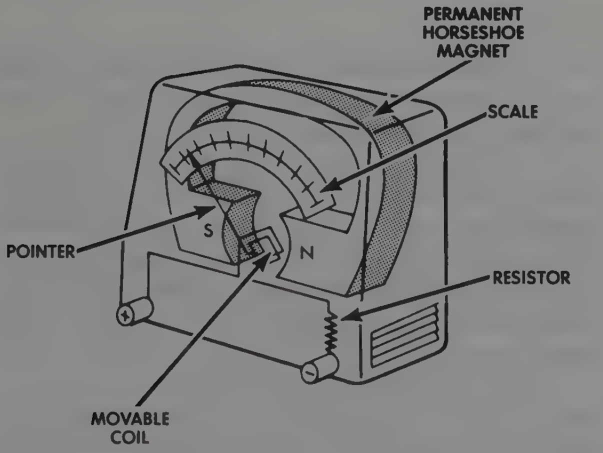


Figure 4-1. Inside view of a voltmeter. (Courtesy of Delco Remy, Division of General Motors Corporation)

CAUTION: In using a voltmeter, always begin by selecting the highest scale. The accuracy of the readings obtained from the voltmeter depends upon the accuracy of the meter used. Voltmeter scales are usually divided into .1 volt divisions, and voltage specifications for automobiles are often given in .1 volt increments.

A voltmeter connected correctly in a simple circuit is shown in Figure 4-2. **CAUTION: Always connect a voltmeter across the circuit in parallel and with the correct polarity: positive (+) to positive (+) and negative (−) to negative (−).**

The voltmeter measures the difference in electrical pressure between the points where the voltmeter *leads* are attached. The voltmeter in Figure 4-2, for example, will indicate the difference in voltage from one side of the light bulb to the other side of the light bulb. (Also see the discussion that follows under the heading of "Measuring Voltage Drop.")

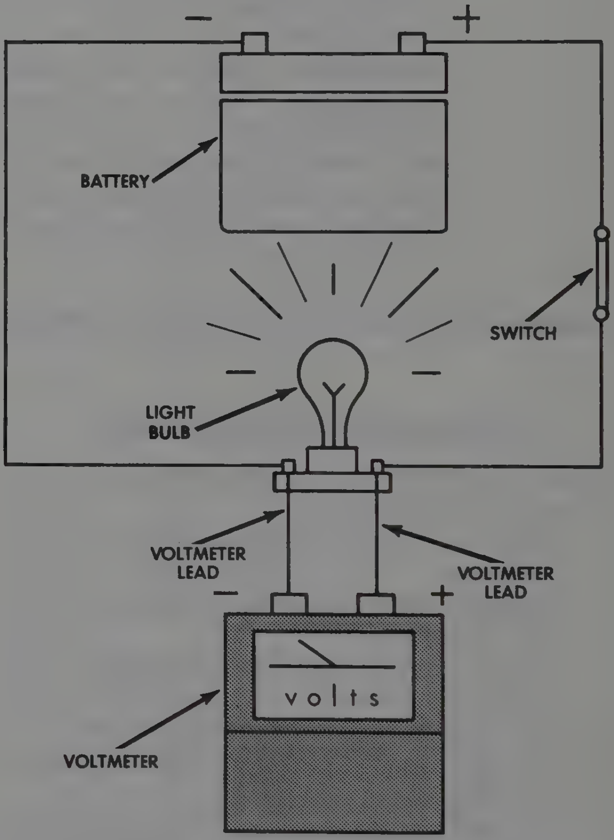


Figure 4-2. A voltmeter is always connected across the circuit in parallel.

Another example of voltmeter use is shown in Figure 4-3. Test procedures may call for the voltmeter to be connected across a battery to measure *available voltage*. The difference in electrical pressure between the two *battery terminals* is the available voltage. (Specifications in the test procedure tell how much voltage should be available.)

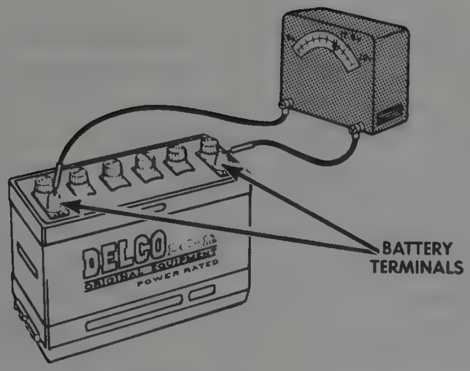

BATTERY
TERMINALS
DELCO
ORIGINAL EQUIPMENT
POWER RATED

Figure 4-3. A voltmeter is connected across a battery to measure available voltage. (Courtesy of Delco Remy, Division of General Motors Corporation)

CAUTION: When using a voltmeter, always consider it a resistor, and remember that current takes the path of least resistance. Figure 4-4 illustrates the *path of least resistance.* If the switch is closed, battery current can flow across the *switch* to *ground*. A voltmeter connected as shown will read zero. The reason for this is that the current goes through the low resistance of the switch and avoids the high resistance of the voltmeter.

If the switch is open, current cannot flow across the switch to ground. Instead it must flow through the voltmeter to ground. The voltmeter will therefore indicate a voltage.

Measuring Voltage Drop. Another use of a voltmeter is to measure *voltage drop*, which is the voltage measured across any component in a circuit. *Voltage drop is affected by the amount of resistance in an electrical component.* If the electrical component offers little resistance to current flow, there will be very little voltage drop, and the voltmeter will show very little voltage. If the electrical component offers a lot of resistance, a large amount of voltage drop will be measured. Voltage drop, then, is a measurement of voltage and a rough indication of the amount (great or small) of

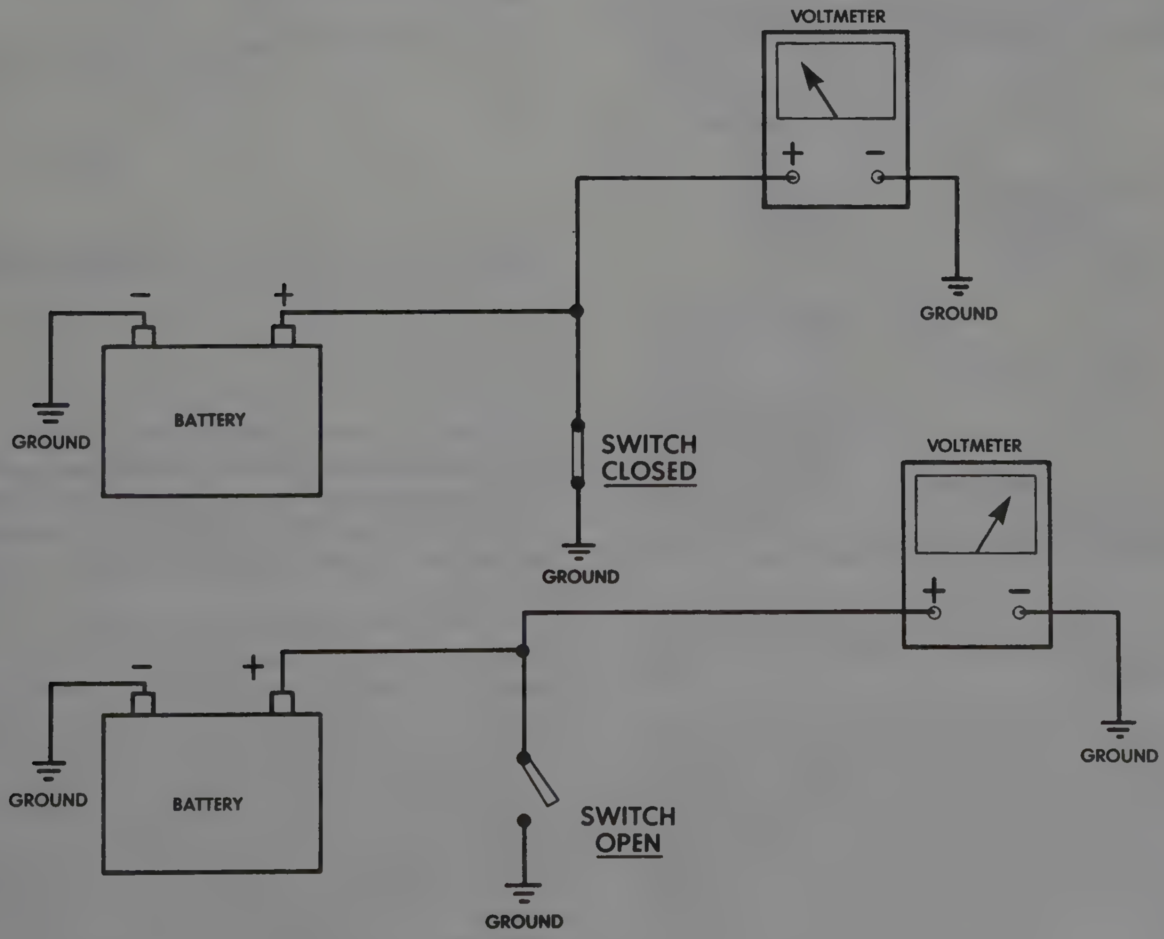

VOLTMETER
+
−
GROUND
−
+
GROUND
BATTERY
SWITCH
CLOSED
GROUND
VOLTMETER
+
−
−
+
GROUND
GROUND
BATTERY
SWITCH
OPEN
GROUND

Figure 4-4. Voltage readings with the switch open and the switch closed.

resistance in a component or circuit. For example, if electrical connections are loose or corroded, they will offer greater resistance and the voltage drop across them will be great. Figures 4-5 and 4-6 illustrate the use of a voltmeter to check voltage drops.

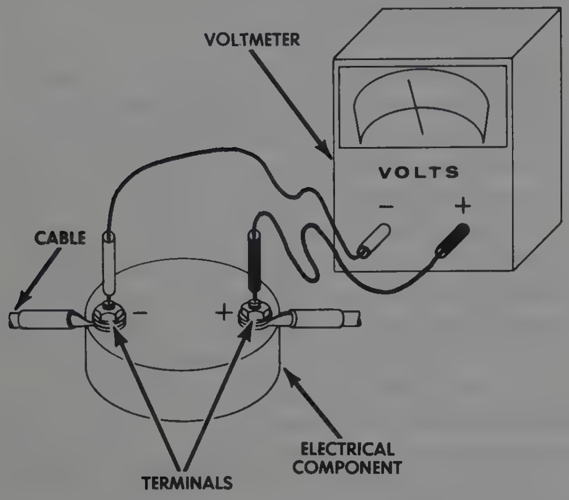


Figure 4-5. Voltage measured across two terminals of an electrical component shows voltage drop.

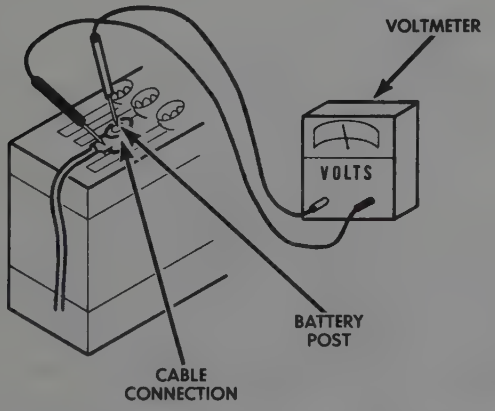


Figure 4-6. Voltage measured across a battery post and cable connection shows voltage drop.

Ammeter

Amperage, or current, is the flow of electrons in an electrical circuit. The instrument used to measure amperage is an **ammeter**. The unit of measurement for amperage is the *ampere* (A). An inside view of an ammeter is shown in Figure 4-7. Like a voltmeter, an ammeter uses a *permanent horseshoe magnet* and *movable coil*. However, the current flow through the ammeter differs from that of a voltmeter. A low-resistance path called a *shunt* is connected in parallel with the movable coil. The shunt conducts the majority of current being measured. Only a small amount of current takes the higher-resistance path through the movable coil. Current flow in the movable coil reacts to the magnetic field of the permanent horseshoe magnet, causing the movable coil to move. A *pointer* connected to the movable coil turns with the movable coil across the *scale*, or the range. The pointer and scale are calibrated to measure the total current.

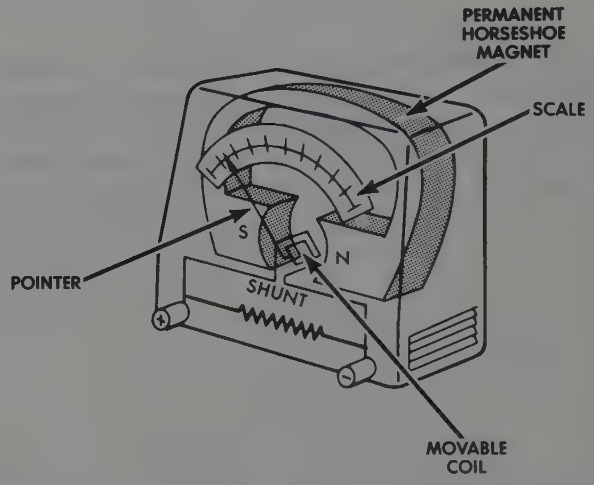


Figure 4-7. Inside view of an ammeter. (Courtesy of Delco Remy, Division of General Motors Corporation)

CAUTION: Ammeters must always be connected in series with a circuit and with correct polarity. The ammeter has a very low resistance. Connecting it in parallel, the way a voltmeter is connected, would damage it.

For amperage to be measured, the circuit must be disconnected, or broken, and the ammeter connected in series. Like the voltmeter, the ammeter has *leads* for connecting it into a circuit. The correct connection for an ammeter is shown in Figure 4-8. Some ammeters have different scales, or ranges. A selector switch on the ammeter changes the value of the shunt resistance used in the ammeter circuit. **CAUTION: Always start measuring current using the highest range on the ammeter.**

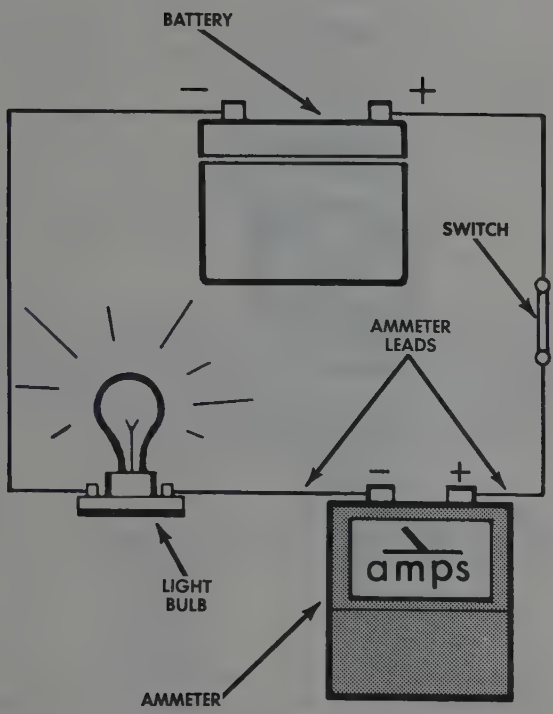


Figure 4-8. An ammeter is connected into a circuit in series.

Ohmmeter

Opposition to the flow of electrons in an electrical circuit is *resistance*. The unit of measurement for resistance is the *ohm* (abbreviated using the Greek letter, *omega*: Ω). The meter used to measure resistance is an **ohmmeter**. As discussed in this unit under the heading "Measuring Voltage Drop," the amount of resistance can be roughly determined when voltage drop is measured. However, an *ohmmeter* must be used.

An inside view of an ohmmeter is shown in Figure 4-9. Like a voltmeter and ammeter, an ohmmeter also uses a *movable coil* influenced by a *permanent horseshoe magnet*. The internal circuit of the ohmmeter consists of a resistor and a *dry cell* battery connected to the movable coil. The dry cell allows a small amount of current to flow through the component being tested (measured) and through the movable coil. This flow of current is directly related to the amount of resistance. The movable coil and *pointer* move to indicate a value in ohms on the *scale*.

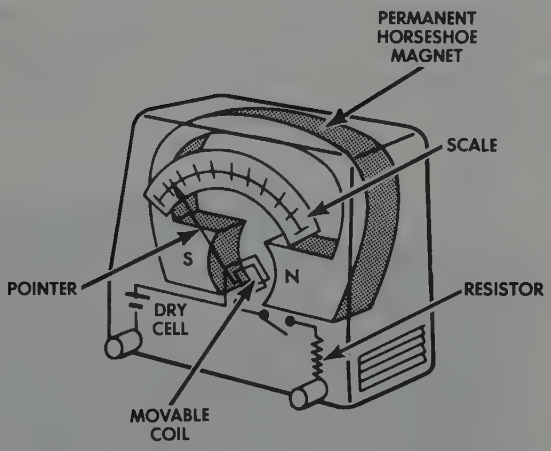


Figure 4-9. Inside view of an ohmmeter. (Courtesy of Delco Remy, Division of General Motors Corporation)

CAUTION: Since an ohmmeter has its own current source, the device to be tested must always be removed from the circuit as shown in Figure 4-10. An ohmmeter must never be connected to an external voltage source or it will be damaged.

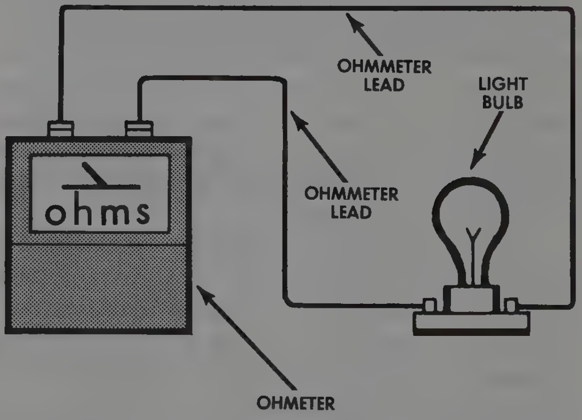


Figure 4-10. An ohmmeter is used to measure resistance of the light after it is disconnected from the circuit.

Before measuring with an ohmmeter, calibrate (adjust) it to zero. Connect the two ohmmeter leads to obtain zero resistance. If the pointer is not on zero, it can be turned to zero with a knob that is usually identified as CALIBRATE. If the ohmmeter will not register zero, the battery is weak and must be replaced.

An ohmmeter usually has a multiple range selector (Figure 4-11) to measure resistance values from zero to infinity. (Infinity is shown on the scale by the mathematic symbol 00.)

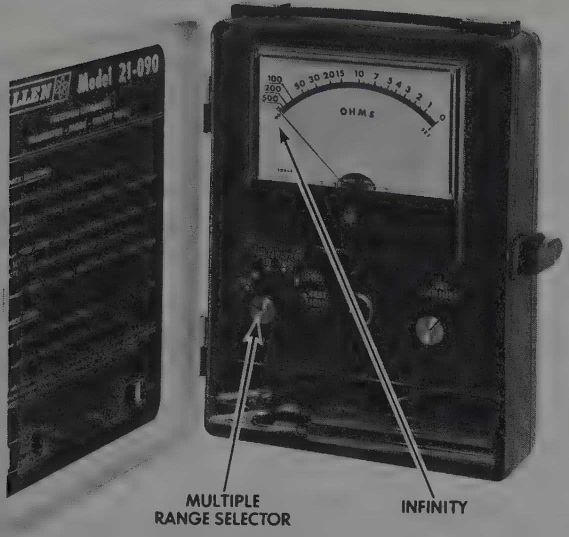


Figure 4-11. An ohmmeter has several operating ranges.

Measuring Continuity. A circuit is a complete path or network of paths that will allow current to flow. In order to have a current flow, the circuit must be unbroken (continuous). Often a tune-up technician must determine whether a circuit is complete, or has *continuity*. The continuity of a circuit or device may be determined with an ohmmeter.

To test for continuity, connect the voltmeter to the component after it is disconnected from the voltage source. If the pointer swings from very high resistance to low resistance, this indicates that the circuit has continuity. If the pointer stays at high resistance and does not move to a lower reading, this indicates a break in the circuit, or a lack of continuity.

Tach-Dwell Meter

One of the most common pieces of equipment in a shop is the **tach-dwell meter**, or tach-dwell tester (Figure 4-12). It combines a dwell meter for measuring breaker point dwell with a tachometer for measuring engine RPM. The use of a tachometer and dwell meter is described in Unit 14.

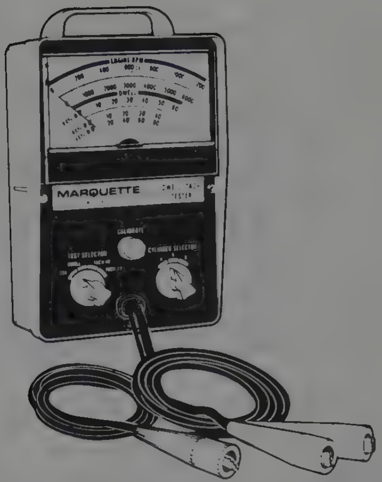


Figure 4-12. Portable tach-dwell meter, or tach-dwell tester. (Courtesy of Marquette Products, Automotive Division of Applied Power, Inc.)

The tach-dwell meter may be combined with an ohmmeter and voltmeter as shown in Figure 4-13. This type of tester allows the technician to make a number of electrical measurements along with the standard tachometer and dwell readings.

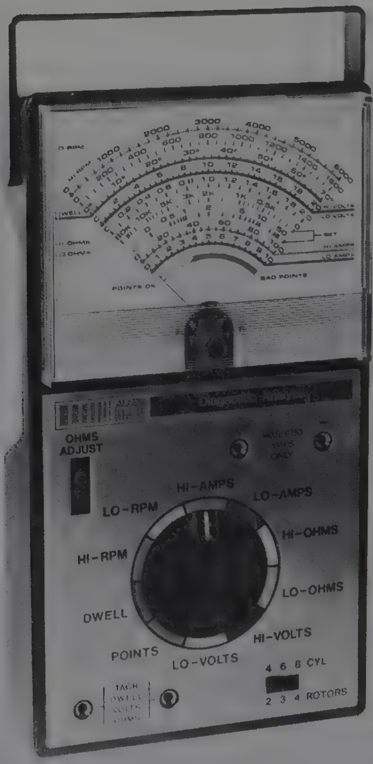


Figure 4-13. A tach-dwell meter may be combined with an ohmmeter and voltmeter.

Timing Light

An ignition **timing light** may be attached to a large engine analyzer or it may be a separate portable unit. Most shops have at least one portable timing light like the one shown in Figure 4-14. The timing light is used to check and adjust basic timing. The use of a timing light is described in Unit 14.

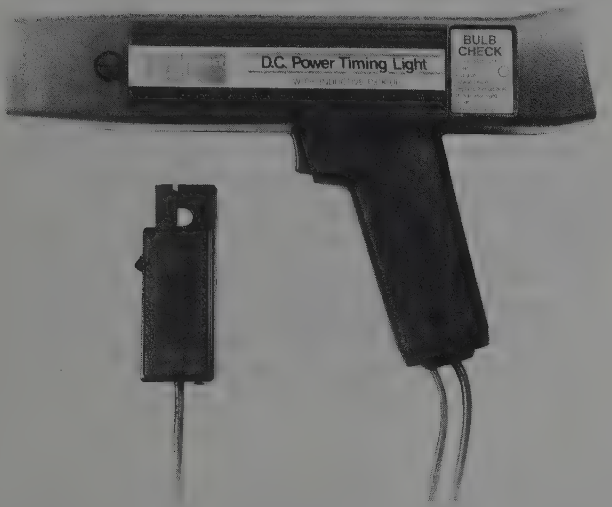

BULB CHECK
D.C. Power Timing Light

Figure 4-14. A portable timing light is used to set basic timing.

Oscilloscope

Another valuable electrical measuring instrument used during a tune-up is the **oscilloscope** (Figure 4-15). When connected to an automotive ignition system, an oscilloscope displays a pattern of the changing voltages in the ignition system on the oscilloscope screen. A technician can observe the pattern and determine what, if any, ignition component is malfunctioning.

Principles of Operation. A simplified cross section of an oscilloscope's *cathode ray tube* is shown in Figure 4-16. An *electron* gun located at the rear senses voltage (signals) in the ignition system and shoots a stream of electrons (referred to as an *electron beam*) at a *screen* in the front of the cathode ray tube. As the electrons hit the screen, a small spot of light results. The screen has a special coating so that the light is "held" momentarily. There are two sets of plates: one set of *horizontal deflection plates* and another set of *vertical deflection plates*. The plates are charged in such a way as to deflect, or bend, the stream of electrons.

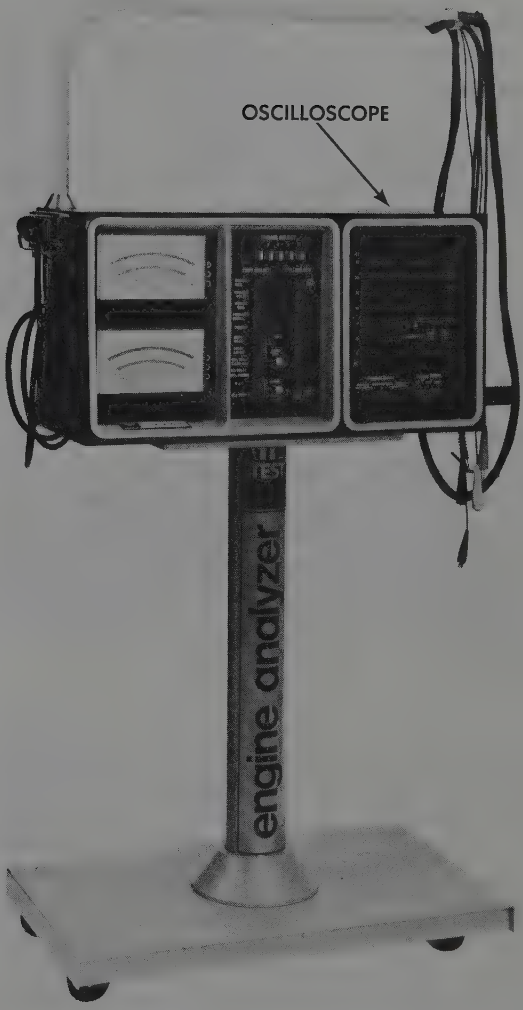

OSCILLOSCOPE
engine analyzer

Figure 4-15. The oscilloscope on this engine analyzer can be used to display a pattern of the changing voltages in an ignition system.

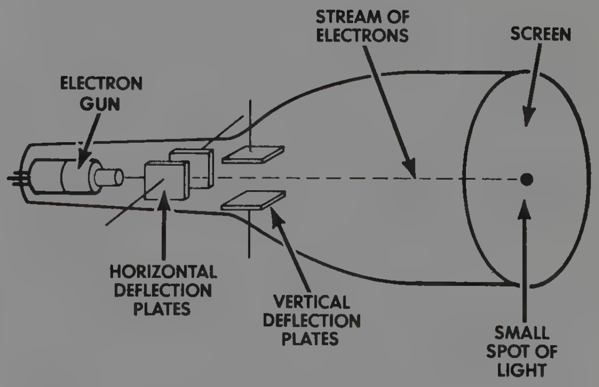

STREAM OF ELECTRONS
SCREEN
ELECTRON GUN
HORIZONTAL DEFLECTION PLATES
VERTICAL DEFLECTION PLATES
SMALL SPOT OF LIGHT

Figure 4-16. Simplified cross section of an oscilloscope's cathode ray tube.

The horizontal deflection plates cause the beam to deflect across the horizontal axis of the screen. As the electron beam sweeps, it leaves a line of light, called a *trace* or *pattern*, on the screen. Each time an electrical signal triggers the start of a horizontal electron beam sweep, it moves across the entire screen and stops until triggered again. Each triggered impulse restarts the electron beam at the left side of the screen regardless of whether the electron beam has completed its sweep across the screen or not.

The vertical deflection plates receive a charge that is in proportion to the changes in voltage of the ignition system being tested. The changing voltages deflect the electron beam vertically as it sweeps from left to right. The combination of horizontal and vertical bending of the electron beam results in a trace, or pattern, on the screen. The pattern represents the amount and time of voltage changes that take place in the ignition system.

Screen Layout. To interpret an oscilloscope pattern (also referred to as *scope pattern*), a tune-up technician must understand the layout of the screen on which the pattern appears. Each oscilloscope manufacturer has a slightly different screen layout, but all layouts have the following features in common (Figure 4-17):

Horizontal lines are printed across the face of the screen. One of these lines is identified as the *zero line*, *base line*, or *plug line*. On most oscilloscopes, this line is on the bottom of the screen and is used to position the scope pattern vertically so that accurate voltage measurements can be made. Each of the horizontal lines above and below the zero lines represents an amount of voltage. Since high voltages are present in the ignition system, the lines represent a number of kilovolts (KV). A kilovolt is one thousand volts. A line marked with the number 5 on the screen represents 5,000 volts (1,000 x 5 = 5,000). The screen shown in Figure 4-17 has the axis on the left marked "25 KV" and the

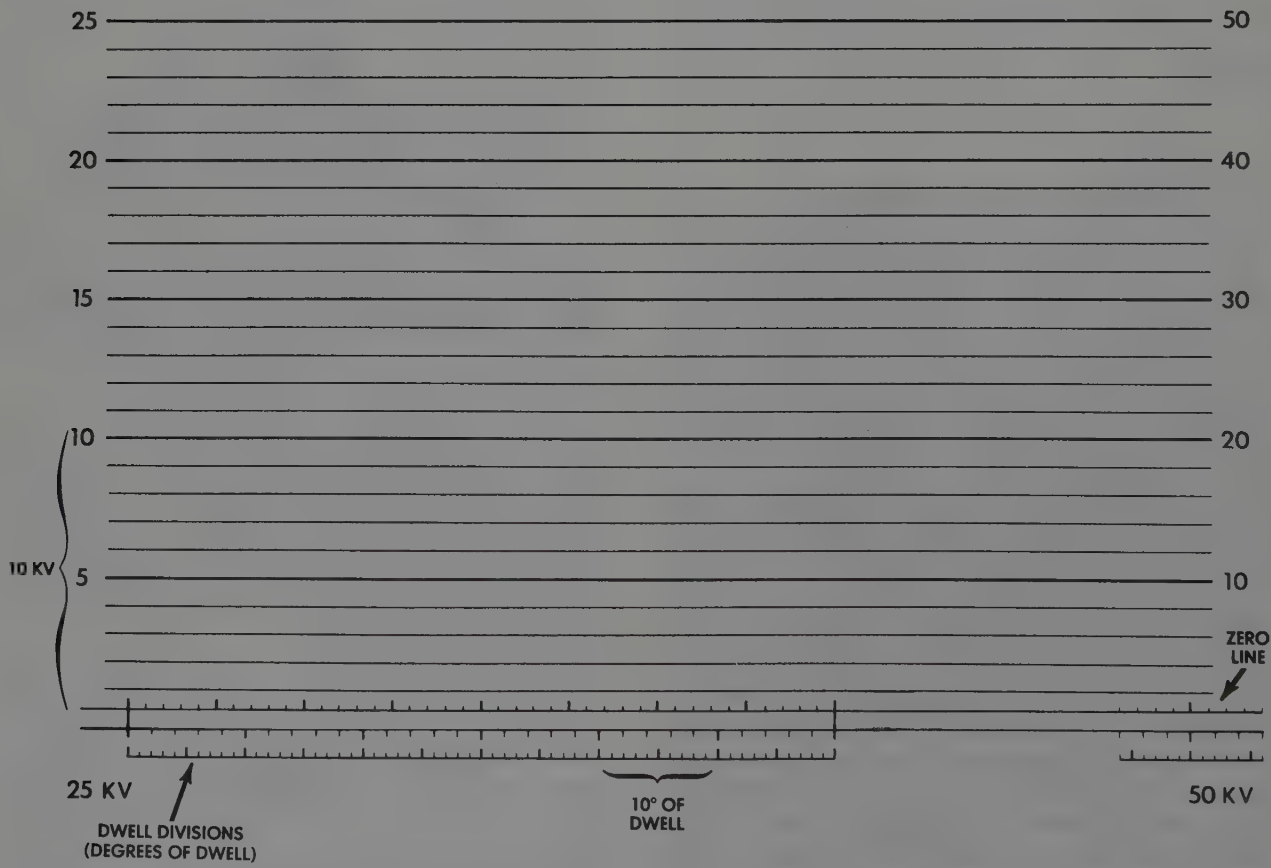


Figure 4-17. Layout of the oscilloscope screen. (Courtesy of Marquette Products, Automotive Division of Applied Power, Inc.)

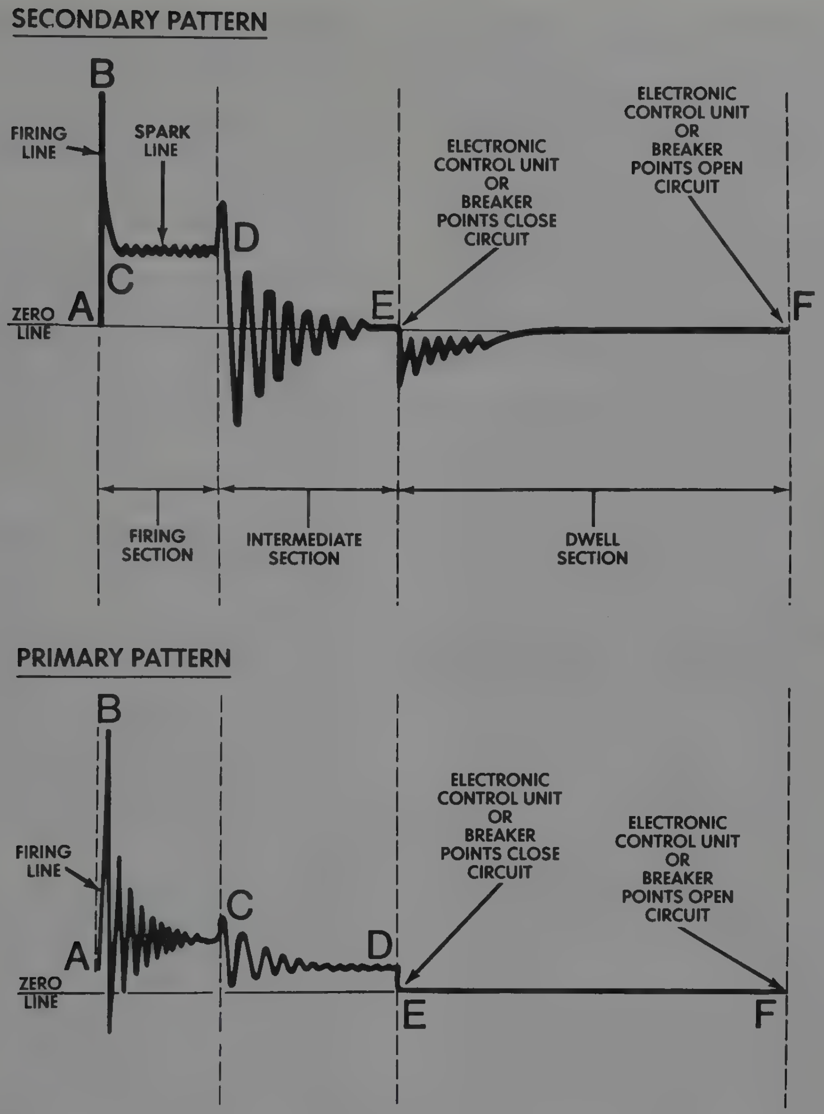

SECONDARY PATTERN
B
FIRING LINE
SPARK LINE
D
C
ZERO LINE
A
E
ELECTRONIC CONTROL UNIT OR BREAKER POINTS CLOSE CIRCUIT
ELECTRONIC CONTROL UNIT OR BREAKER POINTS OPEN CIRCUIT
F
FIRING SECTION
INTERMEDIATE SECTION
DWELL SECTION
PRIMARY PATTERN
B
FIRING LINE
A
ZERO LINE
C
D
E
ELECTRONIC CONTROL UNIT OR BREAKER POINTS CLOSE CIRCUIT
ELECTRONIC CONTROL UNIT OR BREAKER POINTS OPEN CIRCUIT
F

Figure 4-18. Typical primary and secondary pattern. (Courtesy of Nissan Motor Corporation)

axis on the right marked "50 KV." These markings represent two separate ranges. The appropriate scale is selected on the oscilloscope control panel to use either range. The maximum voltage that can be measured with the 25 KV range is 25,000 volts and the maximum voltage with the 50 KV scale is 50,000 volts.

EXAMPLE: If a trace, or pattern, extends from the zero line up to the 10 KV line, the voltage registered is 10 KV or 10,000 volts.

The horizontal axes on the bottom of the screen are divided into increments (*dwell divisions*) referred to as *degrees of dwell*. Dwell is the number of degrees the distributor cam rotates from the time the points close until they open again. The dwell divisions provide a means of measuring and comparing time in degrees of dwell on oscilloscope patterns.

EXAMPLE: If a line on the pattern extends from the 10° mark to the 20° mark, the event has taken 10° of dwell time.

Some newer scopes have a special operating mode which can actually show the trace in relation to the number of milliseconds it takes to occur.

Scope Patterns. When the oscilloscope is connected to an ignition system, the ignition primary circuit or the ignition secondary circuit can be viewed. A *primary pattern* and *secondary pattern* (also called *waveforms*) are shown in Figure 4-18.

Both the primary and secondary patterns are divided into three distinct sections: the *firing section*, the *intermediate section*, and the *dwell section*. The two patterns are very similar, since the voltages in the primary circuit directly affect those in the secondary. Effective use of the oscilloscope depends on understanding what these two basic patterns mean in terms of ignition system operation. Using the oscilloscope is simply a matter of comparing these patterns to any abnormal pattern to pinpoint a problem. This will be described in Unit 14.

The ignition system *secondary pattern* is most useful when evaluating engine performance. Look again at the secondary pattern in Figure 4-18. At point A, the breaker points open, or the electronic control unit breaks the primary circuit. The line from point A to point B, called the *firing line* (or *spike*), shows the high voltage induced in the ignition coil secondary windings as the primary circuit magnetic field collapses. This firing line represents the voltage required to push current through all the resistances (the ignition coil wire, the rotor gap, the spark plug cable or wire, the spark plug, and the spark plug gap or air gap) in the secondary circuit. Since the ignition coil will produce only as much voltage as is needed to overcome all the resistances in the secondary circuit, the height of the firing line shows the electrical condition of the ignition system.

The line from point B to point C is not significant to pattern observation for the tune-up. However, what it is showing is a drop in voltage after current starts to flow across the spark plug gap.

The line from point C to point D, called the *spark line*, represents the actual current flow (*spark*) across the spark plug gap. The voltage of this spark line is lower than that of the firing line, because once all the air gaps have been ionized, less voltage is required to maintain current flow. *Ionized* means that the air molecules between the air gaps are electrically charged.

At point D, there is no longer enough energy left in the ignition coil to maintain current flow across the spark plug gap. However, there is enough energy left in the ignition coil to "bounce" back and forth between the condenser and the secondary windings. These oscillations are represented between points D and E.

At point E, the *breaker points* or the *electronic control unit* closes the circuit, and battery current begins to flow again through the primary circuit. This induces the small oscillations immediately following point E. The circuit remains closed from point E to point F. During this time, the primary winding builds up its magnetic field.

The secondary pattern should show a single point-open signal; a firing line, or spike, of about 8 KV to 10 KV; and a relatively level and smooth spark line. There must be at least five coil-condenser oscillations and at least five oscillations immediately following the point closing. The dwell section should be smooth, with no upward spikes, until the breaker points or electronic control unit break the primary circuit.

The *primary pattern* (again refer to Figure 4-18) has the same three sections as the secondary: firing, intermediate, and dwell. This pattern, however, is developed by much lower voltage than the secondary voltage. Most scopes display the primary patterns on a 400-volt or 500-volt scale. At point A, the breaker points or the electronic control unit opens the primary circuit, and the magnetic field collapses across the secondary windings, inducing a high voltage in them.

The high-voltage firing line from point A to point B represents the high voltage developed in the primary windings as the magnetic field collapses in the secondary winding. This voltage is usually 100 volts or more and occurs because the secondary's collapsing magnetic field induces a voltage in the primary windings themselves. However, since there are many more turns, or windings, in the secondary, the voltage developed there will be much higher than the voltage in the primary winding.

The period from point B to point C represents the high-frequency energy oscillations that occur in the primary circuit while the spark plug is firing. The spark plug stops firing at point C, because the ignition coil no longer has enough energy left to keep the spark flowing. However, there is still a considerable amount of energy left in the ignition coil, and it "bounces" back and forth between the coil windings and the condenser during the period from point C to point D.

At point D, the breaker points close (or the control unit activates), and battery current once again flows through the primary circuit. This continues through the dwell period, point E to point F, and a magnetic field again builds up in the primary windings. Then the whole cycle begins at point A when the primary circuit is interrupted once again.

The primary pattern should show a symmetrical, cone-shaped pattern for the firing section containing about 15 oscillations. Also, the first spike should point upward. The intermediate section should contain about seven oscillations with the first spike pointing upward. The point-close signal should be a single downward drop. In the superimposed mode (a discussion of types of display patterns follows), it should be relatively steady. In the raster mode, the point-close signals for all cylinders should form a relatively straight vertical line. Finally, the dwell section should be a smooth line, free of any upward spikes or oscillations until the breaker points open or the electronic control unit activates.

Types of Display Patterns. The technician has the option of viewing a primary or secondary pattern. Patterns can be displayed a number of different ways (and are therefore called *display patterns*). Usually a selector switch on the oscilloscope allows the display patterns to be viewed on *parade*, *shift* (expanded), *raster*, or *superimposed*.

The *parade* display pattern presents the basic oscilloscope patterns for each cylinder in one continuous line. A parade display pattern for a six-cylinder, in-line engine that is operating correctly is shown in Figure 4-19. Each cylinder is represented by a complete pattern. The cylinders are represented in their firing order from left to right across the screen. The circled numbers below each pattern identify which cylinder that pattern represents.

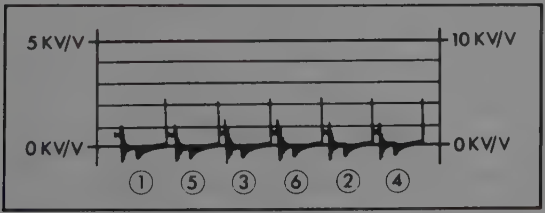


Figure 4-19. Parade display pattern for an in-line, six-cylinder engine with a firing order of 1, 5, 3, 6, 2, 4. (Courtesy of Chevrolet Motor Division, General Motors Corporation)

NOTE: *The circled numbers show the cylinder firing order for this explanation but do not appear on the screen.* The firing order for this engine is 1, 5, 3, 6, 2, 4. It should be noted that the firing line for the No. 1 cylinder will appear at the extreme right of the display, because most oscilloscopes use the signal of No. 1 to trigger the oscilloscope to start a new trace.

Most oscilloscopes having the ability to display a parade pattern also have the ability to expand, or *shift*, the pattern for any one cylinder. An expanded, or shift, display pattern for one of the cylinders is shown in Figure 4-20. This capability allows the close inspection of the pattern for any cylinder.

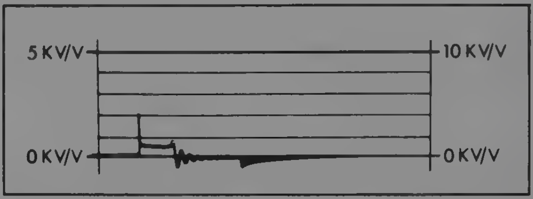


Figure 4-20. Expanded (or shift) display pattern for one cylinder. (Courtesy of Chevrolet Motor Division, General Motors Corporation)

The *raster* display pattern shown in Figure 4-21 shows each cylinder for a six-cylinder, in-line engine on a separate line. The bottom pattern on most oscilloscopes shows the pattern for the No. 1 cylinder. The patterns appearing above that pattern show the remaining cylinders in their firing order. The circled numbers appearing above each pattern are for reference only and identify each cylinder in its firing order. The raster display pattern also allows all the cylinders to be viewed in an expanded, or shift, display pattern for comparison.

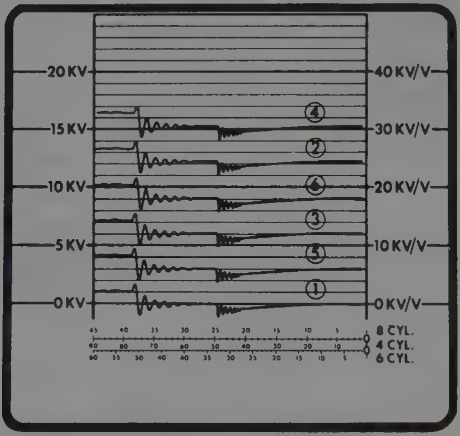


Figure 4-21. Raster display pattern, which shows the patterns on separate lines. (Courtesy of Chevrolet Motor Division, General Motors Corporation)

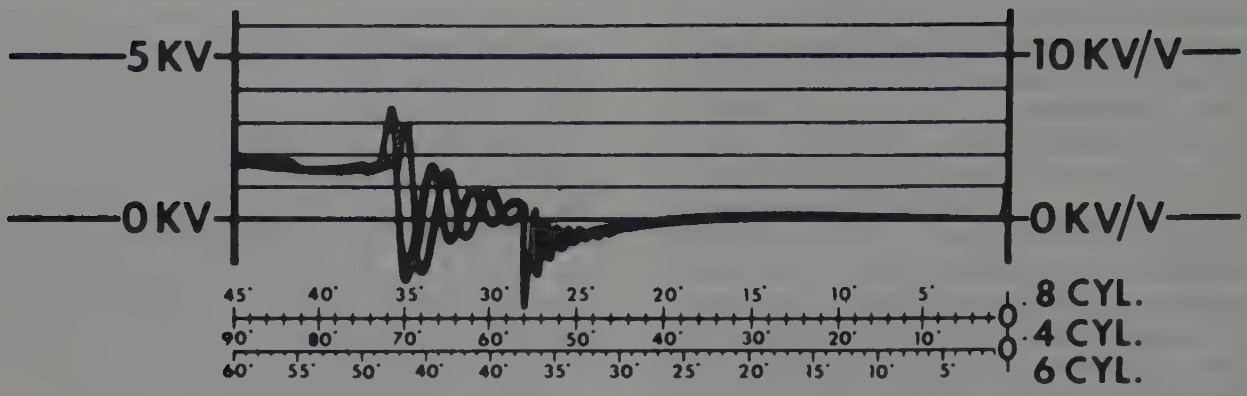


Figure 4-22. Superimposed display pattern, which shows the patterns on top of each other. (Courtesy of Sun Electric Corporation)

Many oscilloscopes have a *superimposed* display pattern (Figure 4-22), in which all the cylinder patterns are displayed on top of each other — that is, superimposed on each other. If each cylinder has the same pattern as the next cylinder's pattern, all the patterns together will look like a single pattern. If, however, one of the cylinders has a different pattern, it will be easily visible when superimposed with the others.

With many oscilloscopes, the spark plug firing lines can be seen only in the parade display pattern selection. The firing lines are not shown in the superimposed or raster selection.

Dynamometer

The **dynamometer**, also called the chassis dynamometer, is used in conjunction with other test equipment at many service facilities (Figure 4-23). It allows the tune-up technician to simulate various driving conditions to help determine the vehicle's performance under such conditions.

A dynamometer is useful for testing vehicle components such as brakes, drive lines, and fuel systems. It is also used to check power output, engine condition, and the operation of the ignition system. Testing and adjusting under actual working loads is the surest way to isolate and repair problems.

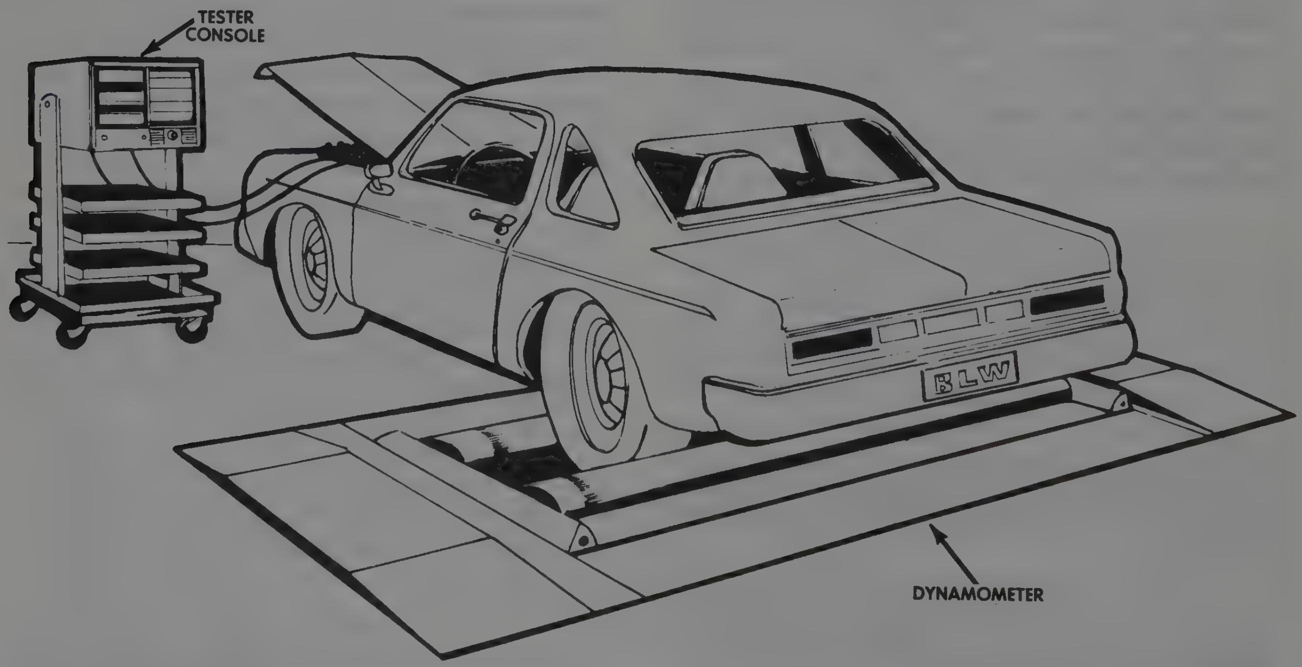


Figure 4-23. A dynamometer is used in conjunction with other testing equipment. (Courtesy of Clayton Manufacturing Company)

Principles of Operation. The dynamometer simulates road conditions when the *drive wheels* of the vehicle are positioned between two large rollers called the *idler roller* and *drive roller* as shown in Figure 4-24. The shaft of the drive roller, sometimes called the forward roller, is attached to a *power absorption unit*. The power absorption unit works like a hydraulic fluid coupling. It has a rotor with blades which throw fluid (water) forward. A stator with stationary blades receives the force of the water flow from the rotor. The power absorption unit acts like a brake. The more water is in the unit, the more power is required to revolve the rotor at any given speed.

As in any brake, when power is absorbed, heat is generated. To dissipate the heat, the water in the power absorption unit is circulated around a number of *tubes* (heat exchangers) through which cooling water flows. The tubes transfer the heat to the cooling water. Dynamometers today are equipped with a thermostatically controlled valve called a *flow control valve* that automatically regulates water flow through the heat exchanger.

When the vehicle's engine is started, the tune-up technician, in the driver's seat, puts the car in gear. The drive wheels turn the two large rollers. The technician adjusts the load on the drive wheels by varying the amount of water within the power absorption unit. The adjustment is accomplished by two valves (*load valve* and *unload valve*) operated remotely from a portable control unit. The ON button allows water to flow into the power absorption unit to simulate any type of road condition required — a level highway, moderate hills, or steep grades. When the OFF button is pushed, water flows out of the power absorption unit, decreasing the load.

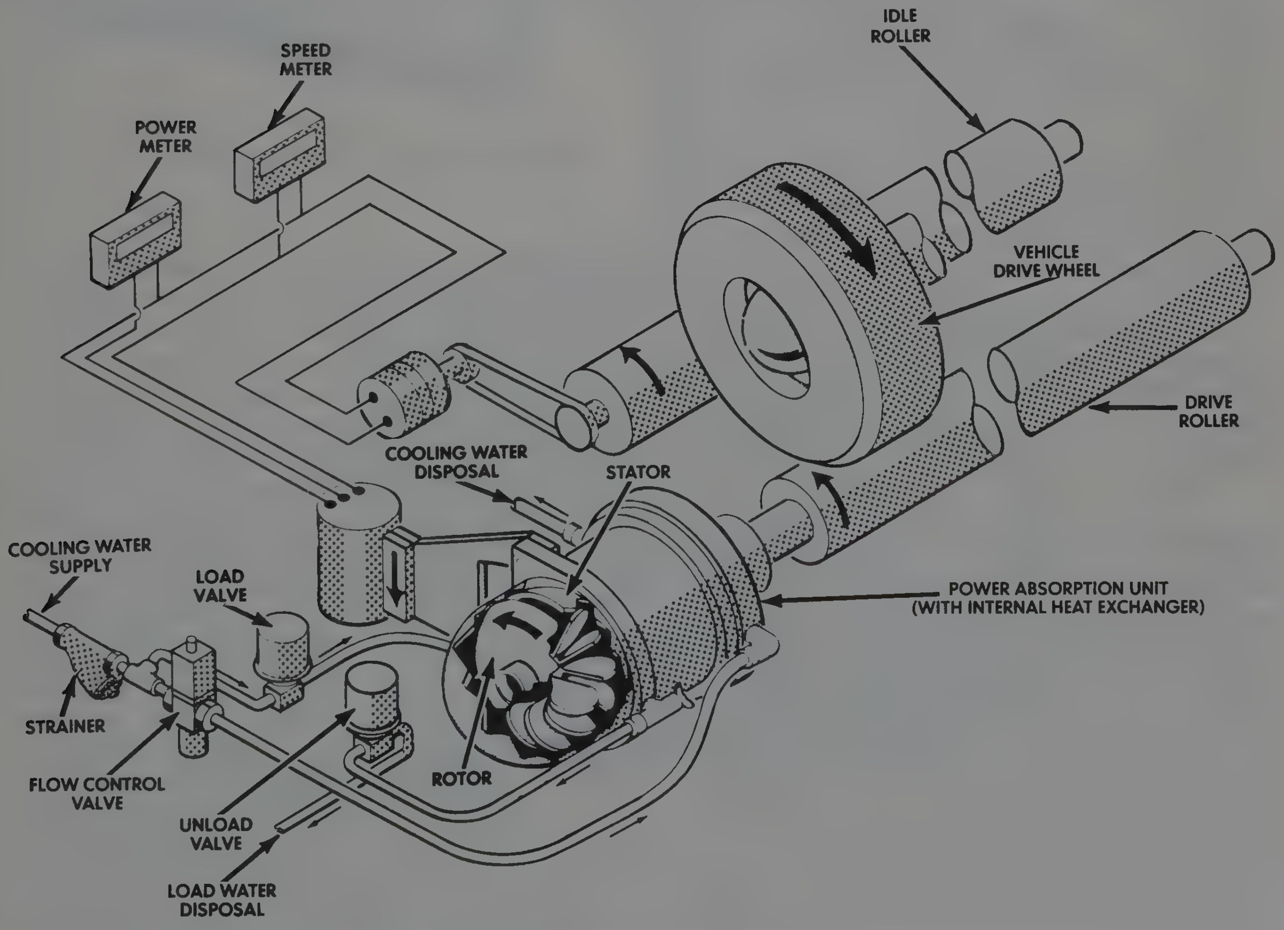

IDLE ROLLER
SPEED METER
POWER METER
VEHICLE DRIVE WHEEL
DRIVE ROLLER
COOLING WATER DISPOSAL
STATOR
COOLING WATER SUPPLY
LOAD VALVE
POWER ABSORPTION UNIT (WITH INTERNAL HEAT EXCHANGER)
STRAINER
FLOW CONTROL VALVE
ROTOR
UNLOAD VALVE
LOAD WATER DISPOSAL

Figure 4-24. Principles of operation of a dynamometer. (Courtesy of Clayton Manufacturing Company)

Using the Dynamometer. Dynamometer testing usually involves the testing and diagnosis of complete vehicle function and its systems. Usually a lengthy test report form is filled out by the tune-up technician as the various vehicle systems are evaluated.

The ignition system testing is conducted with an oscilloscope that is normally supplied by the dynamometer manufacturer as an optional piece of equipment. (The oscilloscope's operation was explained earlier in this unit.) The advantage of using a dynamometer during ignition system testing is that a specific problem can be isolated by simulating the road conditions under which the problem occurs.

Typically, tests are conducted under at least one of the following five operating conditions or a combination of them:

1. Full throttle, low speed.
2. Full throttle, high speed.
3. Part throttle, low speed.
4. Part throttle, high speed.
5. Acceleration between low and high speed conditions.

NOTE: Full throttle conditions simulate hill climbing at various steepnesses of grade, while part throttle conditions simulate level road conditions.

Ignition system difficulties uncovered by oscilloscope patterns under any of these simulated conditions are corrected, and then the tests are repeated to make sure the difficulties are solved.

It is also possible to make adjustments while the vehicle is under a specific load condition. For example, the basic timing can be adjusted on a vehicle while it is "loaded" to simulate a steep hill.

Exhaust Analyzers

During a tune-up, the engine's exhaust gases are sampled and measured to determine that exhaust emissions are at specified acceptable levels. The equipment used to sample the exhaust gases is called an **exhaust analyzer**. A typical exhaust analyzer is shown in Figure 4-25. It samples exhaust gases and provides meter readings in percent (%) of carbon monoxide (CO) and parts per million (PPM) of hydrocarbon (HC) emissions. Meter scales and test functions are selected on the *control panel*. Exhaust analyzers use an infrared light source to analyze an exhaust gas sample. The amount of CO and HC is determined by the amount of infrared energy absorbed by the gas sample.

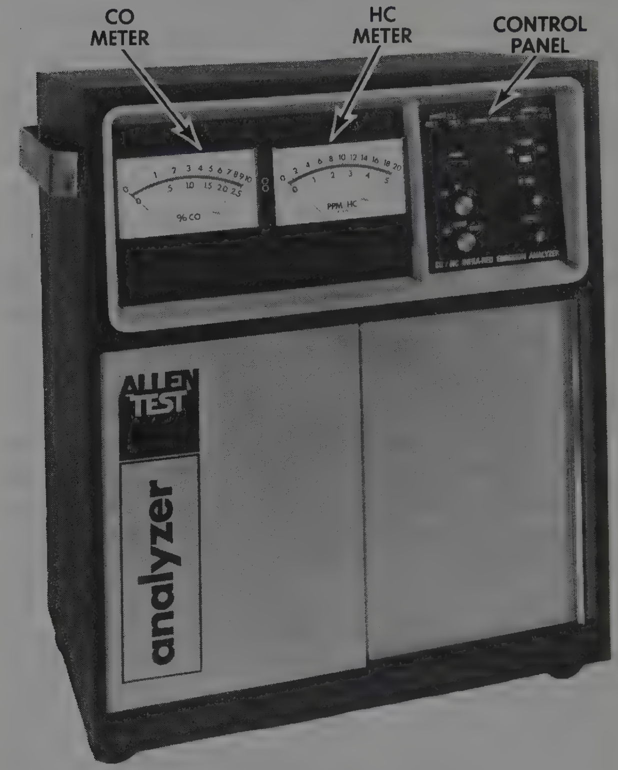


Figure. 4-25. Typical exhaust analyzer.

The air-fuel mixture affects the reading on the *CO meter*. The higher the % CO reading, the richer the air-fuel mixture. For example, if the vehicle has a choke stuck closed, an idle mixture screw that is turned out too far, a restricted air cleaner, or an extremely high float level in the carburetor, the CO meter will reflect this by a high reading. An abnormally high CO level can only be due to an excessively rich air-fuel mixture, which is a function of the carburetion or fuel injection systems. On the other hand, a low CO level indicates a lean air-fuel mixture.

The *HC meter* on the analyzer indicates the amount of unburned fuel leaving the combustion chamber. As mentioned, the HC meter shows the amount of hydrocarbons (HC) on a scale divided into parts per million (PPM). This means that if the exhaust sample were divided into 1 million parts, the scale shows how many of the million parts would be hydrocarbons.

If all of the gasoline is not being burned in the combustion chamber, raw gasoline (HC) will go out the tail pipe and register on the HC meter.

For example, a fouled spark plug, a defective spark plug wire, or burned valves will cause an abnormally high reading on the HC meter, because all of the gasoline going through the cylinder is not burned. An excessively rich air-fuel mixture will also increase the HC level. NOTE: *A rich air-fuel mixture will show up sooner on the CO meter than on the HC meter.*

A lean air-fuel mixture produces the lowest CO emissions. However, if the mixture is too lean, the engine will misfire intermittently or totally. This misfiring may not be heard, but it is present any time the exhaust analyzer shows a low CO reading and an HC reading that fluctuates between the low and high ends of the scale.

Computerized Testing Equipment

A computerized tester is essentially a diagnostic computer (Figure 4-26) that collects data from scope patterns and meters based on a vehicle's actual operating characteristics. It has the ability to sift through this information automatically and compare it with the parameters stored in its memory bank. It can then deduce in a logical manner which engine parts are defective and need to be repaired or re-

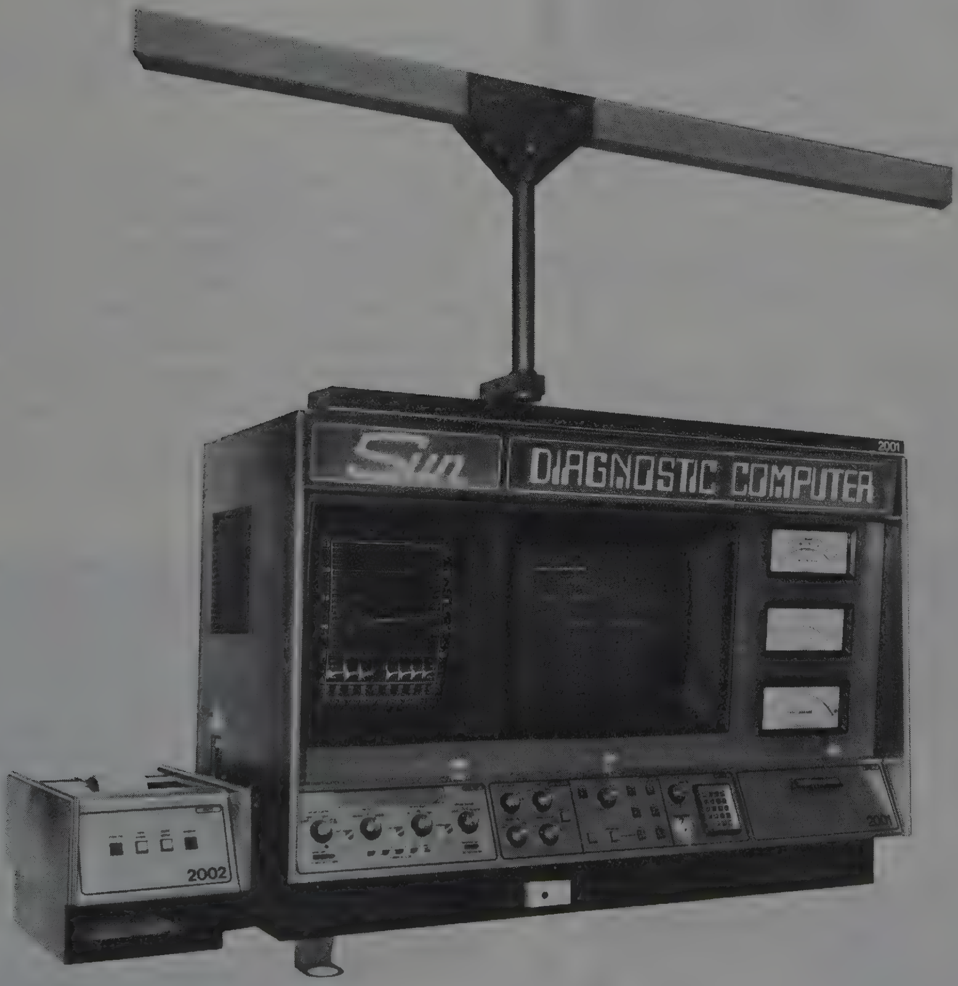


Figure 4-26. Computerized tester. (Courtesy of Sun Electric Corporation)

placed. The computerized tester shows this information on a *display screen* as shown in Figure 4-27. Some units have a *printer* which provides a written record of tests and results. The computerized tester may be used with a dynamometer for complete vehicle diagnosis (Figure 4-28).

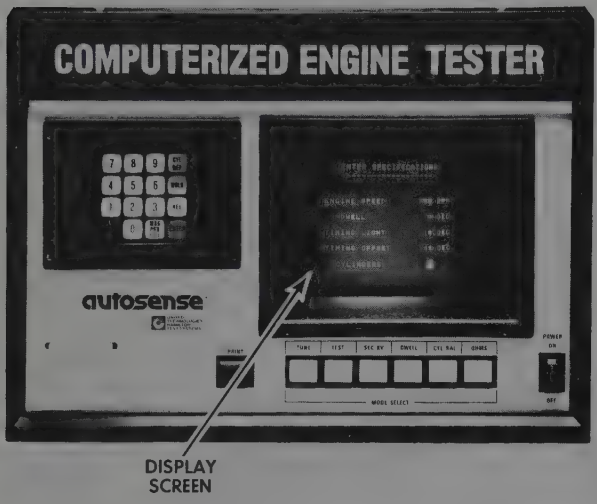

COMPUTERIZED ENGINE TESTER
autosense
PRINT
TUNE
TEST
SEC KV
DWELL
CYL BAL
OHMS
MODE SELECT
POWER ON
OFF
DISPLAY SCREEN

Figure 4-27. Information from meters and oscilloscopes may be shown on a display screen. (Courtesy of United Technologies Hamilton Test Systems)

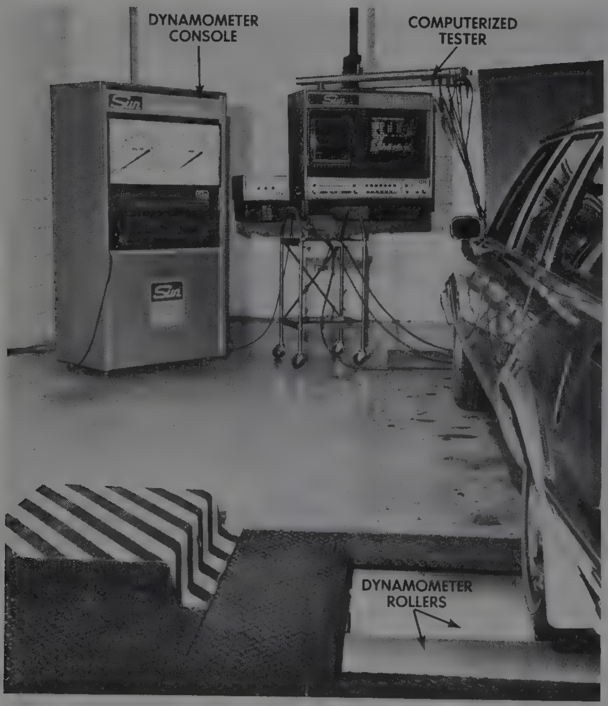

DYNAMOMETER CONSOLE
COMPUTERIZED TESTER
DYNAMOMETER ROLLERS

Figure 4-28. A computerized tester may be used with a dynamometer. (Courtesy of Sun Electric Corporation)

Diagnostic Connectors

Many late-model vehicles are equipped with an electrical connector, called a *diagnostic connector* (Figure 4-29), located in the engine compartment. The diagnostic connector provides access to several test points for the starting, charging, and ignition systems. It is connected to a tester via a *diagnostic connector adapter* (Figure 4-30). This allows the technician to perform tests on circuits without disconnecting any wires. Many tests are made with a voltmeter. However, computerized testing equipment is designed to plug directly into these diagnostic connectors. This makes tester hookup much quicker and easier. Figure 4-31 shows an engine's electrical diagnostic circuitry.

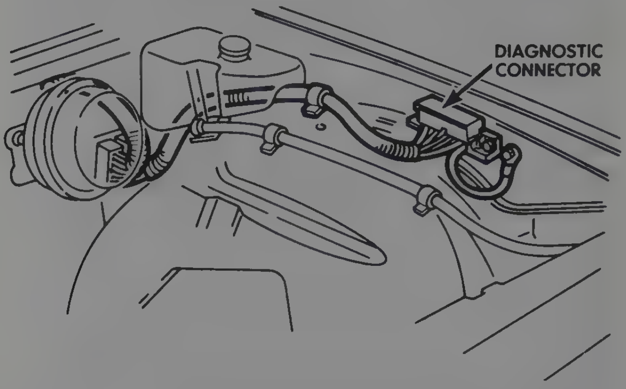

DIAGNOSTIC CONNECTOR

Figure 4-29. Typical engine compartment location for the diagnostic connector. (Courtesy of Chevrolet Motor Division, General Motors Corporation)

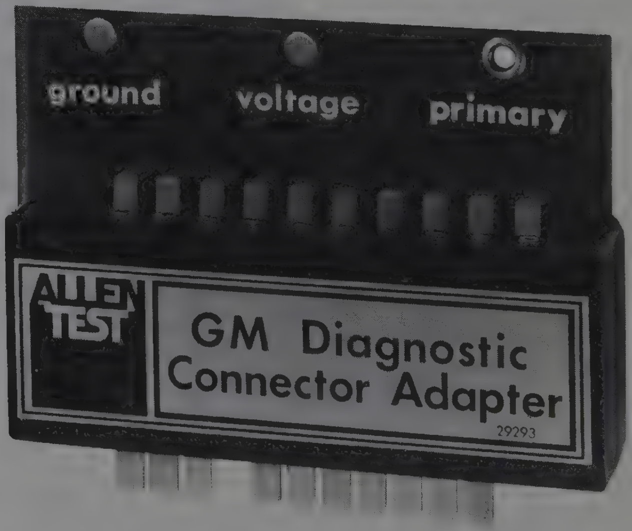

ground
voltage
primary
ALLEN TEST
GM Diagnostic Connector Adapter
29293

Figure 4-30. Diagnostic connector adapters allow quick hookup of testing equipment.

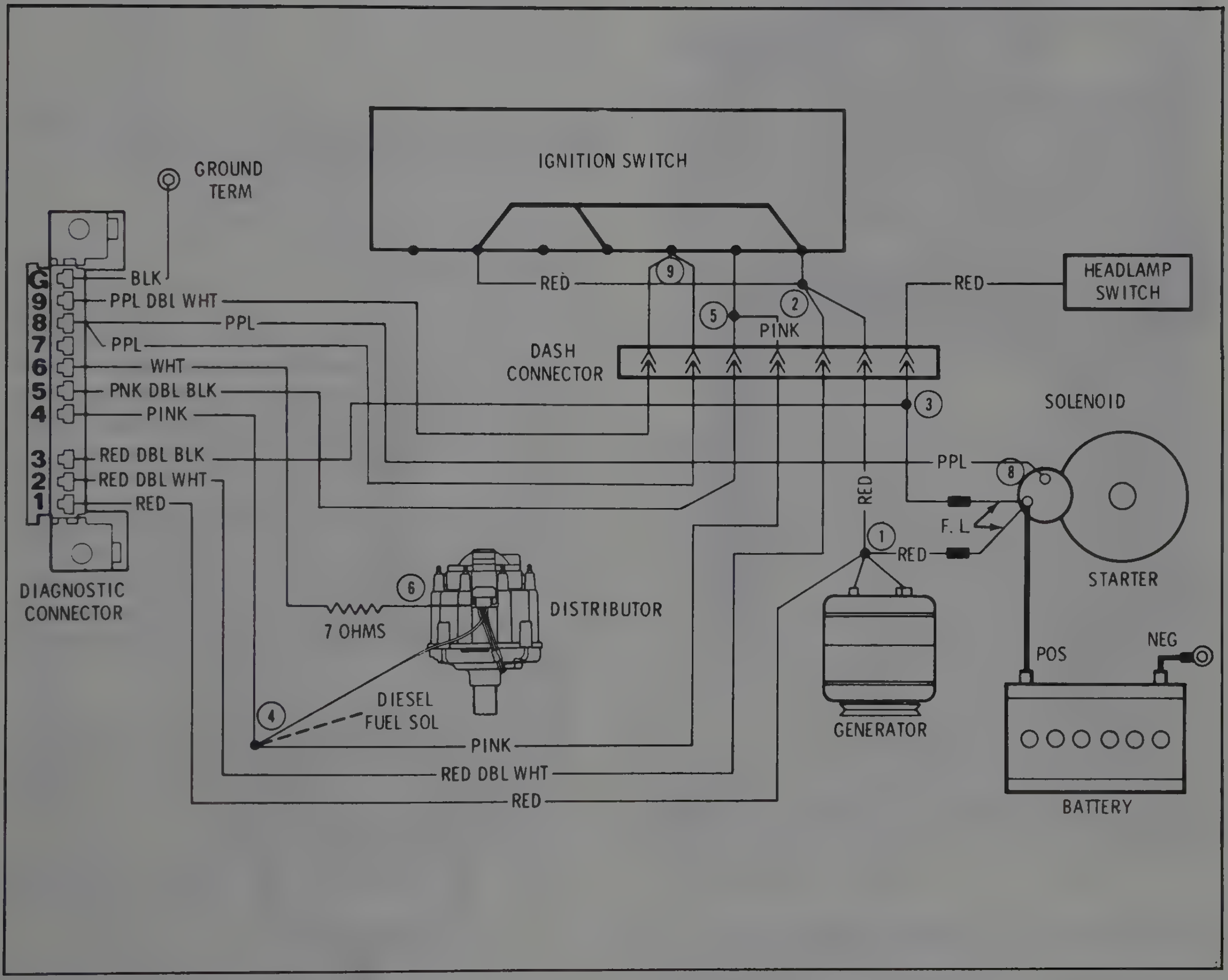

IGNITION SWITCH
GROUND TERM
G
9
8
7
6
5
4
3
2
1
BLK
PPL DBL WHT
PPL
PPL
WHT
PNK DBL BLK
PINK
RED DBL BLK
RED DBL WHT
RED
DIAGNOSTIC CONNECTOR
RED
9
5
2
PINK
DASH CONNECTOR
RED
HEADLAMP SWITCH
3
SOLENOID
PPL
8
RED
F. L
1
RED
STARTER
6
7 OHMS
DISTRIBUTOR
4
DIESEL FUEL SOL
PINK
RED DBL WHT
RED
GENERATOR
POS
NEG
BATTERY

Figure 4-31. An engine's electrical diagnostic circuitry. (Courtesy of Chevrolet Motor Division, General Motors Corporation)

Distributor Tester

The **distributor tester** (Figure 4-32) is a diagnostic tester used for a number of distributor service operations. When a distributor tester is available, the usual practice during a tune-up is to remove the distributor from the vehicle and install it on the distributor tester. The distributor tester is discussed in Unit 15.

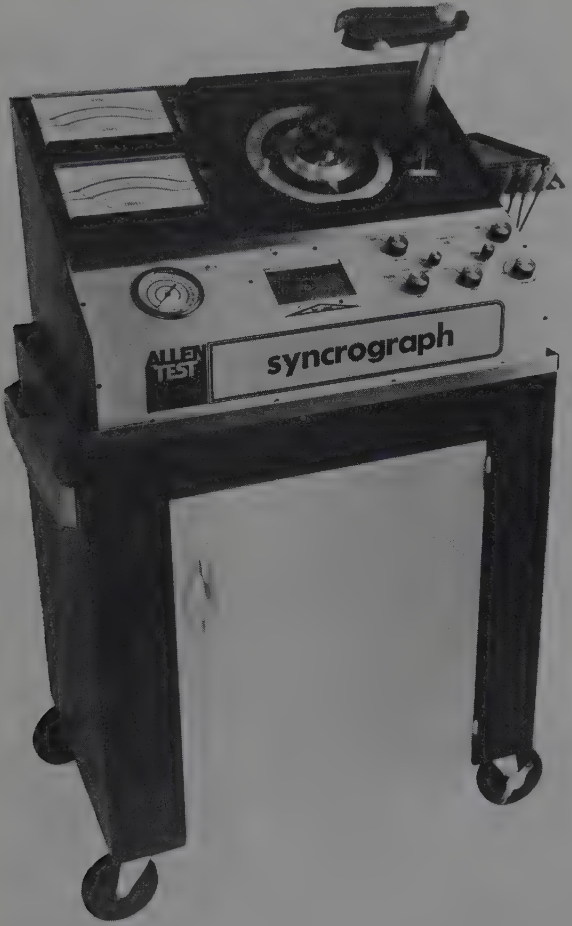


Figure 4-32. Distributors can be serviced on a distributor tester.

MECHANICAL INSTRUMENTS

Although most of the tune-up procedure is performed with electrical testing instruments, some mechanical instruments are also used.

Vacuum Pump

Vehicles have many vacuum-operated parts, which operate in conjunction with various ignition, emission, and fuel system components. Vacuum-operated parts and systems can be checked by connecting them to a hand-operated **vacuum pump** (Figure 4-33), which creates a vacuum for testing. The pump incorporates a *trigger* or *handle* to help develop the vacuum and a *dial gage* to show the amount of vacuum developed.

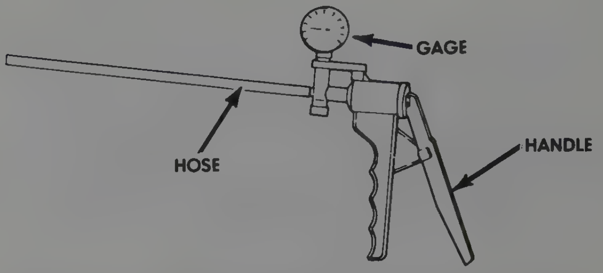


Figure 4-33. A hand-operated vacuum pump is used to provide a source of test vacuum. (Courtesy of Chevrolet Motor Division, General Motors Corporation)

Vacuum Gage

A **vacuum gage** (Figure 4-34) is a *dial gage* with a *vacuum hose* connection. The vacuum hose is attached to a vacuum circuit or to the engine's intake manifold. The amount of vacuum available is then registered on the face of the dial gage in inches of mercury (abbreviated as in. Hg.).

Since the amount of vacuum developed by the engine corresponds to engine condition, the vacuum gage is a useful troubleshooting tool. The use of the vacuum gage to troubleshoot engine condition is described in detail in Unit 7.

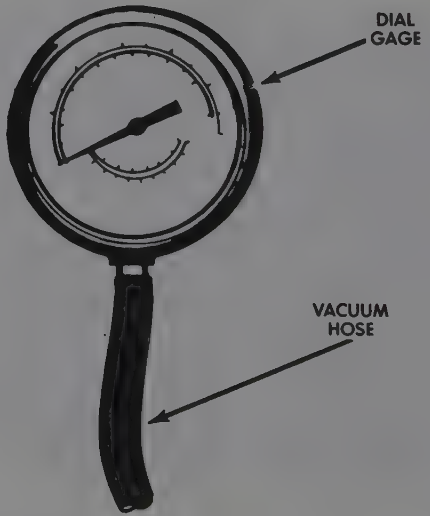


Figure 4-34. A vacuum gage is used to measure engine vacuum. (Courtesy of Ford Motor Company)

Compression Tester

The amount of compression in each of the engine's cylinders helps determine the amount of power developed by that cylinder on its power stroke. Low or uneven compression in the cylinders greatly affects performance. The amount of compression in the engine's cylinders is a very good measure of the engine's overall condition.

The tool used to measure the compression in each of the engine's cylinders is a **compression tester** (Figure 4-35). A compression tester is essentially a *pressure gage* with a *fitting* (push-in type or screw-in type). The fitting is threaded into the spark plug hole or pushed into the spark plug hole depending on the type used. As the engine is cranked, the compression pressure is registered on the pressure gage. The pressure for each cylinder is recorded and compared to engine specifications. The use of a compression tester is discussed further in Unit 7.

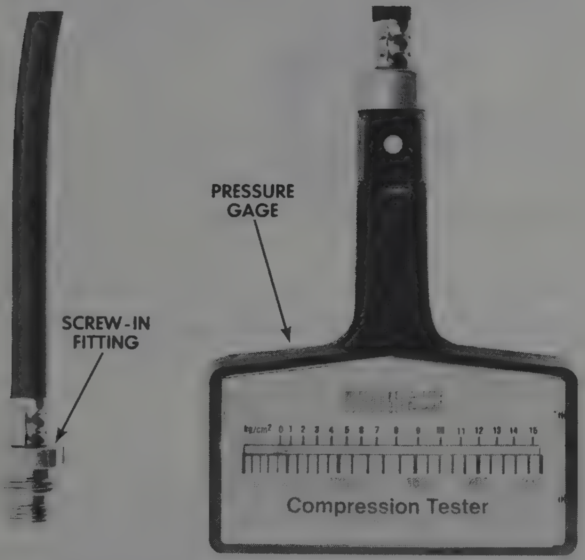


Figure 4-35. Engine compression is measured with a compression tester.

Cylinder Leakage Tester

Another tool useful for determining engine condition is a **cylinder leakage tester** (Figure 4-36). The cylinder leakage tester is used with shop compressed air to determine if there are any leaks from the cylinder when the piston is on the compression stroke. A *top dead center (TDC) indicator* is used on the distributor shaft to get each piston in firing position. A *connection hose* is attached from the cylinder to the tester. Shop compressed air is connected into the tester. The compressed air is regulated when the cylinder is filled. If air leaks past the piston rings or the valves, the leakage is indicated on the dial of the cylinder leakage tester. Its use is covered in detail in Unit 7.

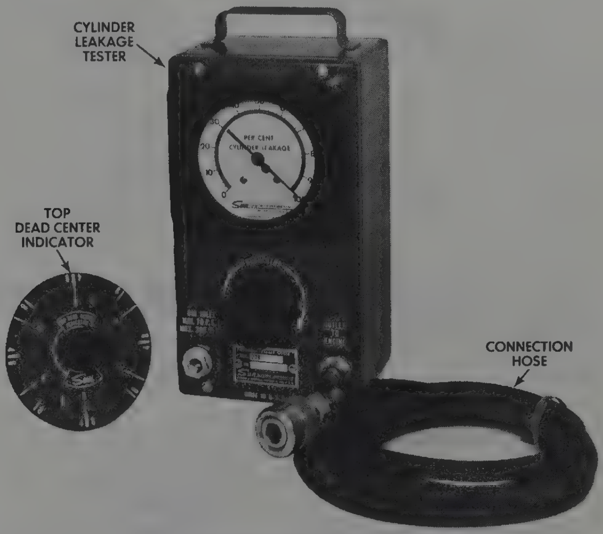


Figure 4-36. Cylinder leakage tester. (Courtesy of Sun Electric Corporation)

Hydrometer

The *state of charge* of the battery is important for good ignition voltage during engine cranking. A **hydrometer** (Figure 4-37) is used to determine the state of charge. The battery vent caps are removed and the hydrometer inserted into the battery cell. A *squeeze bulb* on top of the hydrometer is used to pull battery electrolyte into the glass barrel.

A calibrated float in the glass barrel will float in a position determined by the amount of sulfuric acid in the cell. Numbers on the float allow the technician to determine the battery's state of charge. The hydrometer is discussed in Unit 10 in more detail.

Wire Feeler Gage

The **wire feeler gage** is a precision-ground wire used to accurately determine the space (clearance) between two parts. These gages come in sets of different thicknesses and are used for many jobs, including valve adjustment and spark plug gap setting.

The wire feeler gage shown in Figure 4-38 is used to measure air gaps and to adjust air gaps of spark plugs with a bending attachment. This operation is described in detail in Unit 15.

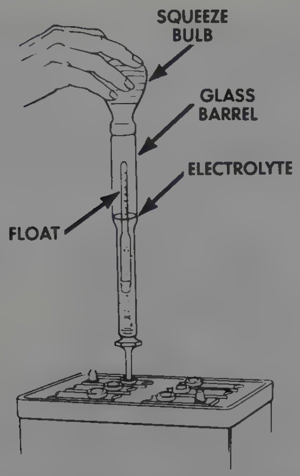


Figure 4-37. The state of charge of a battery is measured with a hydrometer. (Courtesy of Delco Remy, Division of General Motors Corporation)

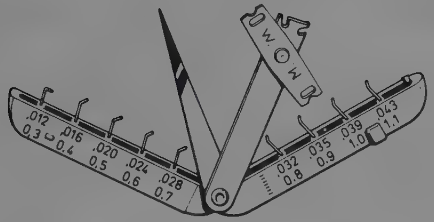


Figure 4-38. Typical wire feeler gage with bending attachment. (Courtesy of Robert Bosch Sales Corporation)

Spark Tester

In order to operate, an engine must have compression, fuel, and ignition. One of the first steps in troubleshooting is to determine if the ignition system is delivering a spark. A **spark tester** (Figure 4-39) is connected to a spark plug wire. The engine is cranked while the tune-up technician observes the spark tester to see if there is a spark. The use of a spark tester is described in more detail in Unit 14.

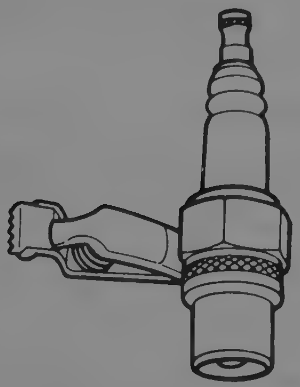


Figure 4-39. A spark tester is used to check the ignition system. (Courtesy of Ford Motor Company)

Cleaning Tank

Many tune-up procedures require that parts be cleaned prior to inspection or repair. Parts may be cleaned in a **cleaning tank** (Figure 4-40). The cleaning tank may contain solvent for general cleaning or a cold dip solution for fuel system parts. The solvent is usually recirculated by a pumping system. **WARNING: Be sure to observe all the safety rules that apply to the type of cleaning tank used.**

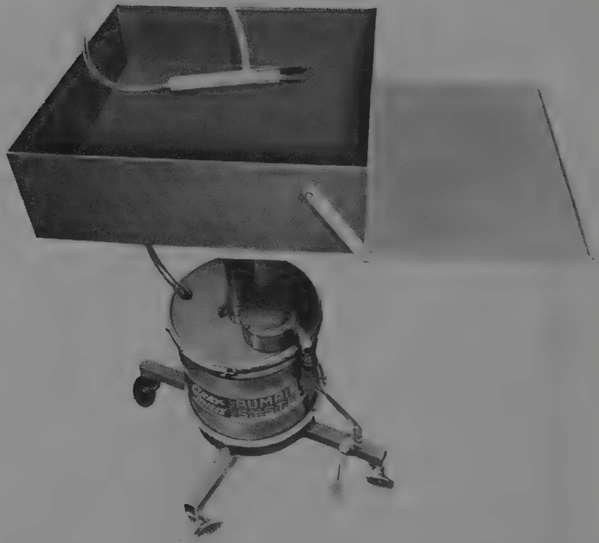


Figure 4-40. A cleaning tank is used to clean parts during a tune-up.

KEY TERMS

Ammeter: An instrument used to measure amperage.

Cleaning tank: A tank containing solvent or cold dip solution used to clean parts.

Compression tester: A tool used to measure the compression in each of the engine's cylinders.

Cylinder leakage tester: A tool used to determine if there are any leaks from the cylinder when the piston is on the compression stroke.

Distributor tester: A diagnostic tester used for a number of distributor service operations.

Dynamometer: A testing device that allows the tune-up technician to simulate various driving conditions to help determine the vehicle's performance ability.

Exhaust analyzer: A tester that uses an infrared light source to analyze an exhaust gas sample.

Hydrometer: A tool used to determine the state of charge of a battery.

Ohmmeter: An instrument used to measure resistance.

Oscilloscope: A diagnostic tester used to trace the voltage patterns on a screen.

Spark tester: A tool that is connected to the end of a spark plug cable to help determine if the ignition system has spark.

Tach-dwell meter: An instrument that combines a dwell meter for measuring breaker point dwell with a tachometer for measuring engine RPM.

Timing light: An instrument used to check and adjust basic timing.

Vacuum gage: A tool used to measure the amount of vacuum in a vacuum circuit or in the engine's intake manifold.

Vacuum pump: A hand-operated pump used to create a vacuum to test vacuum-operated systems and parts.

Voltmeter: An instrument used to measure voltage.

Wire feeler gage: A set of precision-ground wires used to measure the air gap of a spark plug.

SELF-CHECK

1. Why should meter range selectors be set on the highest scale when they are turned on?
2. How is a voltmeter connected?
3. What is voltage drop?
4. How is an ammeter connected?
5. How is an ohmmeter connected?
6. What is a continuity test?
7. What are the three sections of a primary or a secondary scope pattern?
8. What is the difference between a primary and secondary scope pattern?
9. What is shown in the primary firing section?
10. What is shown in the primary intermediate section?
11. What is shown in the primary dwell section?
12. What is a raster display pattern?
13. Why is a dynamometer used to test an ignition system?
14. What is a compression tester used for?
15. How is a cylinder leakage tester used?

DISCUSSION TOPICS AND ACTIVITIES

1. Make a list of the tools and equipment required for a complete tune-up.
2. What are the advantages of a computerized tester?

CERTIFICATION PRACTICE

1. Voltage drop measurements can also be interpreted as an *indication* of the amount of:
   A. Voltage
   B. Amperage
   C. Resistance
   D. Wattage
2. An ammeter must always be connected into a circuit:
   A. Across or in parallel
   B. In series
   C. Either A or B
   D. Neither A nor B
3. An ohmmeter is connected to an electrical device:
   A. In parallel
   B. With voltage applied to the circuit
   C. Only after the device is removed from the circuit
   D. All of the above
4. An ohmmeter may be used to measure:
   A. Resistance
   B. Continuity
   C. Both A and B
   D. Neither A nor B
5. Condenser oscillations are shown on the oscilloscope screen in the:
   A. Firing section
   B. Intermediate section
   C. Dwell section
   D. None of the above

ANSWERS

1: C, 2: B, 3: C, 4: C, 5: B

Unit 5 LOOKING UP TUNE-UP SPECIFICATIONS

One of the most important steps of a tune-up is to determine the correct service procedures and to obtain the correct specifications for a vehicle. Specifications are measurements recommended for components by the vehicle manufacturer. The technician uses the manufacturer's recommended tune-up specifications and step-by-step procedures as a guide for diagnosing a problem and doing the repair.

DEVELOPING JOB COMPETENCIES

When you finish reading and studying this unit, you should be able to:

- Look up specifications in a repair manual or service manual.
- Read a specification chart.
- Use a diagnosis chart to find the source of a problem.

WHERE TO FIND TUNE-UP SPECIFICATIONS

Tune up specifications may be found in *service labels*, *service manuals*, *general repair manuals*, and *service bulletins*.

SERVICE LABELS

Each car manufacturer provides some basic specifications on an under-the-hood emission control information label. This **service label** is mounted in a convenient location (Figure 5-1). It describes the type of emission control equipment used on the vehicle and provides the specifications used in tune-up that affect emission levels. Typical information includes *idle setting*, *hot engine valve lash*, and *timing specifications* (Figure 5-2).

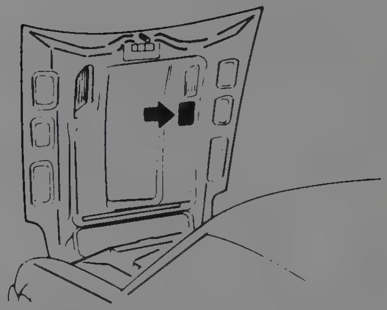
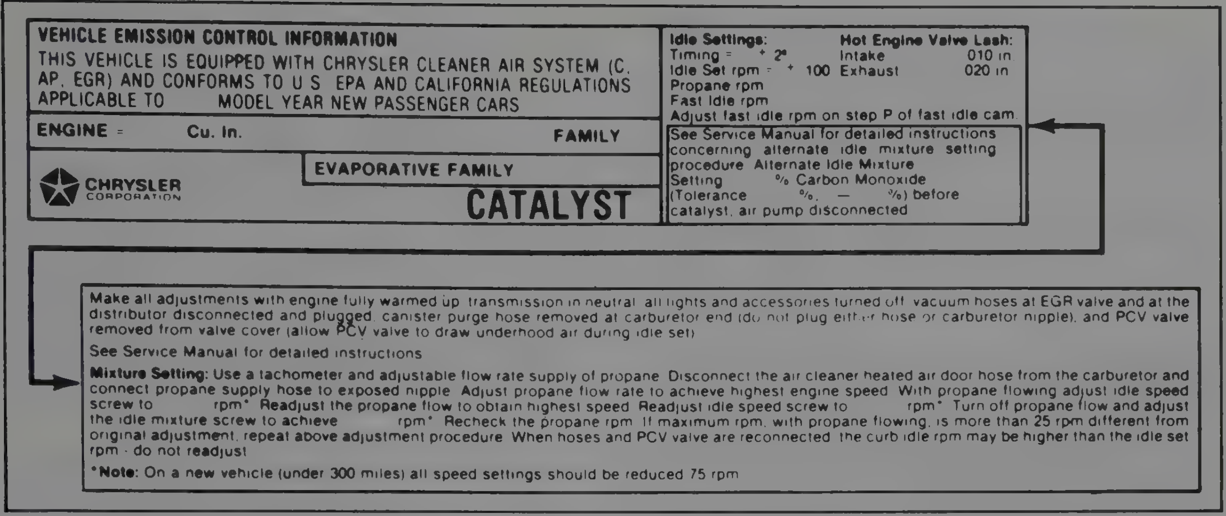


Figure 5-1. Typical location (see arrow) of an under-the-hood emission control. (Courtesy of Nissan Motor Corporation)

An emission vacuum hose routing diagram (Figure 5-3) is often provided. This diagram shows where each of the vacuum hoses should be connected. The technician can follow the diagram to check for proper hose connections or to replace hoses after a repair.

Service Manuals

Complete tune-up specifications, repair procedures, and troubleshooting information can be found in the manufacturer's engine **service (shop) manual** (Figure 5-4). Manufacturer's shop manuals are written by the automotive manufacturer for the mechanics in their dealerships. A shop manual covers a particular model in great detail, sometimes in a number of volumes.



VEHICLE EMISSION CONTROL INFORMATION

THIS VEHICLE IS EQUIPPED WITH CHRYSLER CLEANER AIR SYSTEM (C. AP. EGR) AND CONFORMS TO U S EPA AND CALIFORNIA REGULATIONS APPLICABLE TO MODEL YEAR NEW PASSENGER CARS

ENGINE = Cu. In. **FAMILY**

EVAPORATIVE FAMILY

CHRYSLER CORPORATION

CATALYST

Idle Settings:
Timing = + 2°
Idle Set rpm = + 100
Propane rpm
Fast Idle rpm
Adjust fast idle rpm on step P of fast idle cam.

Hot Engine Valve Lash:
Intake 010 in
Exhaust 020 in

See Service Manual for detailed instructions concerning alternate idle mixture setting procedure Alternate Idle Mixture Setting % Carbon Monoxide (Tolerance %, — %) before catalyst, air pump disconnected

Make all adjustments with engine fully warmed up transmission in neutral all lights and accessories turned off vacuum hoses at EGR valve and at the distributor disconnected and plugged, canister purge hose removed at carburetor end (do not plug either hose or carburetor nipple), and PCV valve removed from valve cover (allow PCV valve to draw underhood air during idle set)

See Service Manual for detailed instructions

Mixture Setting: Use a tachometer and adjustable flow rate supply of propane Disconnect the air cleaner heated air door hose from the carburetor and connect propane supply hose to exposed nipple Adjust propane flow rate to achieve highest engine speed With propane flowing adjust idle speed screw to rpm* Readjust the propane flow to obtain highest speed Readjust idle speed screw to rpm* Turn off propane flow and adjust the idle mixture screw to achieve rpm* Recheck the propane rpm If maximum rpm, with propane flowing, is more than 25 rpm different from original adjustment, repeat above adjustment procedure When hoses and PCV valve are reconnected the curb idle rpm may be higher than the idle set rpm - do not readjust

***Note:** On a new vehicle (under 300 miles) all speed settings should be reduced 75 rpm

Figure 5-2. Typical emission control information label. (Courtesy of Chrysler Corporation)

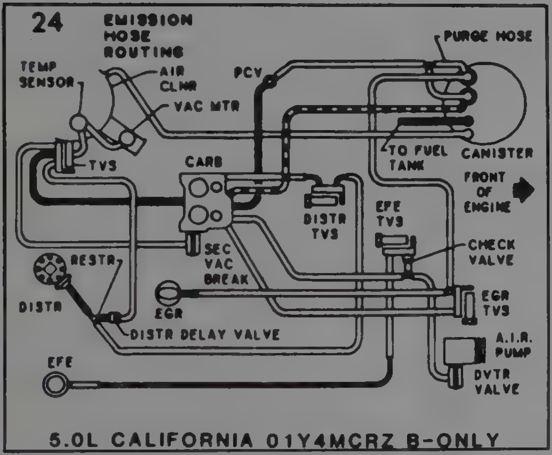


Figure 5-3. An emission vacuum hose routing diagram is often provided on an under-the-hood service label. (Courtesy of Chevrolet Motor Division, General Motors Corporation)

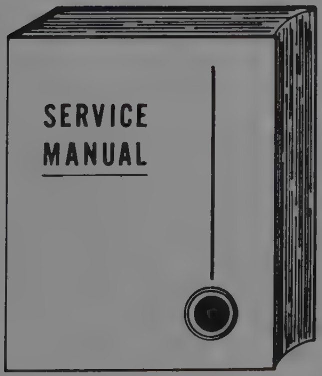


Figure 5-4. Tune-up specifications, repair procedures, and troubleshooting information can be found in a service shop manual.

General Repair Manuals

Several makes, models, and years of vehicles are covered in **general repair manuals** (Figure 5-5). Some manufacturers provide an update service for these manuals. This means that each year new vehicle specifications are provided to update the manual. The general repair manual provides less detailed procedures than a service manual.

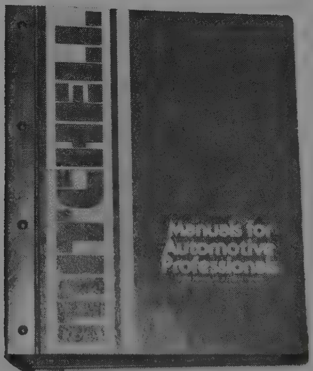


Figure 5-5. A general repair manual covers several makes, models, and years of vehicles.

Service Bulletins

Tune-up repair procedures and specifications change for each model year. In addition, they sometimes change during the model year. A car manufacturer having a recurrent service problem lets dealership mechanics know about it through a **service bulletin**. The service bulletin is usually a one-page or two-page description of a particular service problem and corrective procedure. It is kept in the shop for reference. The bulletins are often sent to magazines and trade journals. In this way, independent garage mechanics can be kept up-to-date.

LOOKING UP SPECIFICATIONS

In order to locate the service information required for a tune-up, the technician must follow two steps:

First, the vehicle and engine must be identified. The make of the vehicle is given by the name (for example, Chevrolet or Ford) on the outside of the vehicle. A particular make of vehicle, however, might be equipped with any one of a number of different engines, each with different tune-up specifications. In order to determine what model engine is in the vehicle, the technician must locate the vehicle identification number (abbreviated VIN). This number is typically located on a plate fastened to the upper left instrument panel area, visible through the windshield (Figure 5-6).

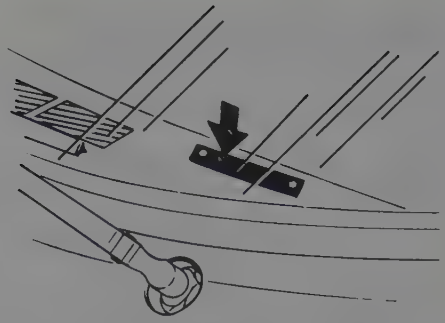


Figure 5-6. Typical location (see arrow) of a VIN plate. (Courtesy of Nissan Motor Corporation)

One group of numbers or letters provides the engine code. The number or letter is matched to a VIN decoding chart like the one shown in Figure 5-7. The decoding chart is shown in each manufacturer's service manual. As shown in this illustration, the VIN letter "A" indicates that this AMC vehicle is equipped with a 258 cubic inch displacement (CID), six-cylinder engine. It has overhead valves (indicated by "O.H.V.") and one venturi (indicated by the "1V").

Vehicle Identification Number (VIN) Decoding Chart

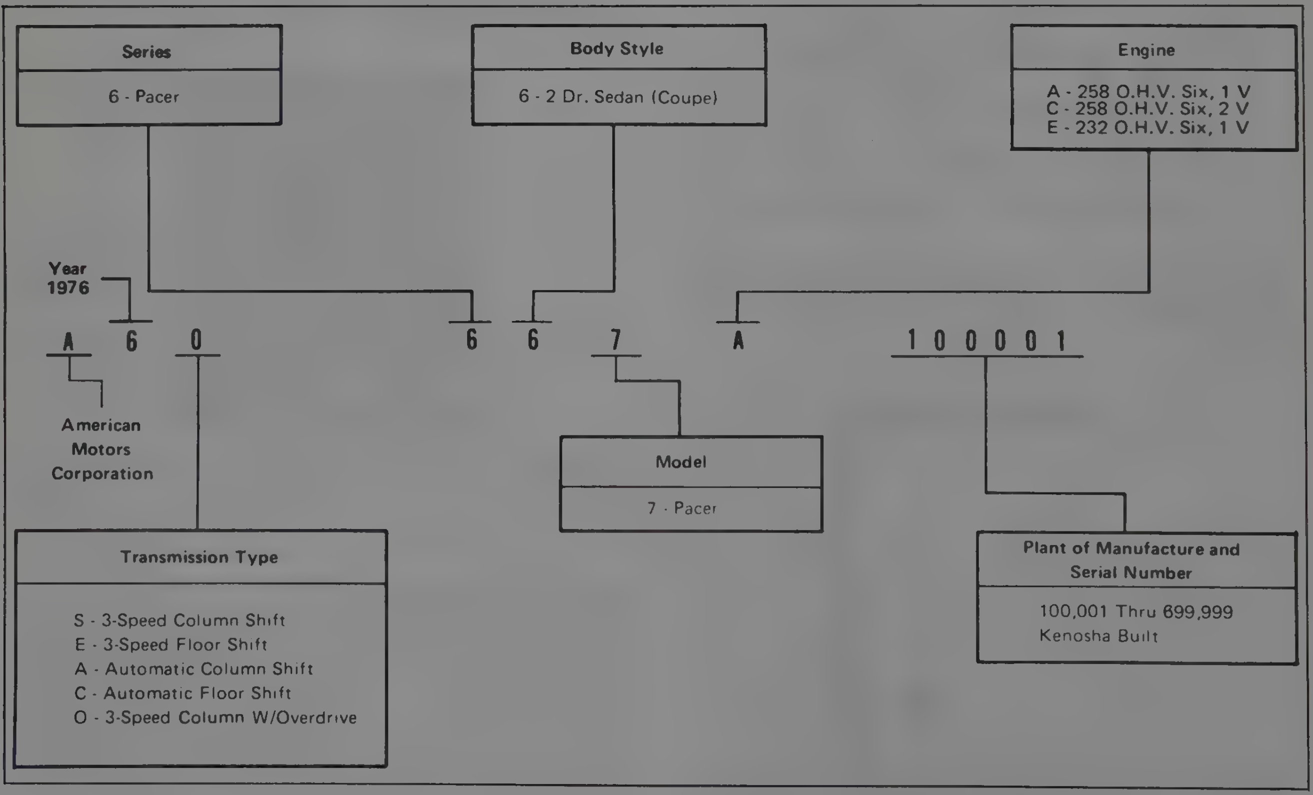
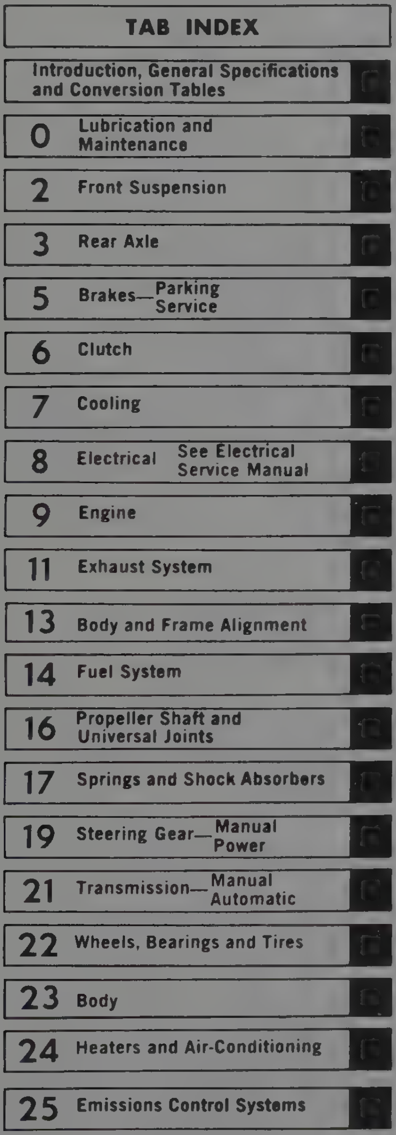

Series
6 - Pacer
Body Style
6 - 2 Dr. Sedan (Coupe)
Engine
A - 258 O.H.V. Six, 1 V
C - 258 O.H.V. Six, 2 V
E - 232 O.H.V. Six, 1 V
Year 1976
A 6 0
6 6 7 A
1 0 0 0 0 1
American Motors Corporation
Model
7 - Pacer
Transmission Type
S - 3-Speed Column Shift
E - 3-Speed Floor Shift
A - Automatic Column Shift
C - Automatic Floor Shift
O - 3-Speed Column W/Overdrive
Plant of Manufacture and Serial Number
100,001 Thru 699,999
Kenosha Built

Figure 5-7. The VIN decoding chart is used to find out what type of engine is in the vehicle and other important data. (Courtesy of American Motors Corporation)

Second, the technician must locate the appropriate shop manual for that vehicle and find the tune-up information in the table of contents, called the *section index* or *tab index* (Figure 5-8). The specifications required for the tune-up are found in three sections: Section 8: Electrical; Section 14: Fuel System; and Section 25: Emission Control Systems. (In the example shown in Figure 5-8, the technician would turn to Section 14.) In each of these sections, three types of information are presented: *step-by-step repair techniques, specification charts,* and *troubleshooting charts.*



TAB INDEX

	Introduction, General Specifications and Conversion Tables
0	Lubrication and Maintenance
2	Front Suspension
3	Rear Axle
5	Brakes—Parking Service
6	Clutch
7	Cooling
8	Electrical See Electrical Service Manual
9	Engine
11	Exhaust System
13	Body and Frame Alignment
14	Fuel System
16	Propeller Shaft and Universal Joints
17	Springs and Shock Absorbers
19	Steering Gear—Manual Power
21	Transmission—Manual Automatic
22	Wheels, Bearings and Tires
23	Body
24	Heaters and Air-Conditioning
25	Emissions Control Systems

Figure 5-8. Tab index for a service manual. (Courtesy of Chrysler Corporation)

Step-by-Step Repair Techniques

In a shop manual, **step-by-step repair techniques** usually explain, with pictures, how to disassemble, repair, reassemble, and adjust the component. These procedures are usually numbered in the order in which they are to be performed (Figure 5-9). Instructions must be followed exactly for the job to be done properly.

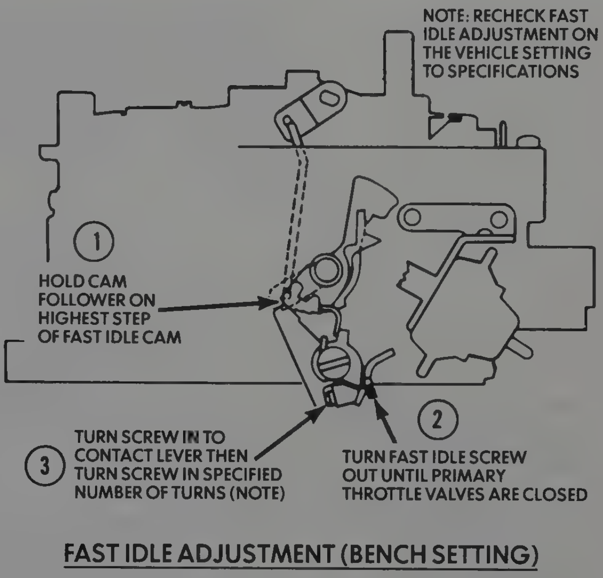
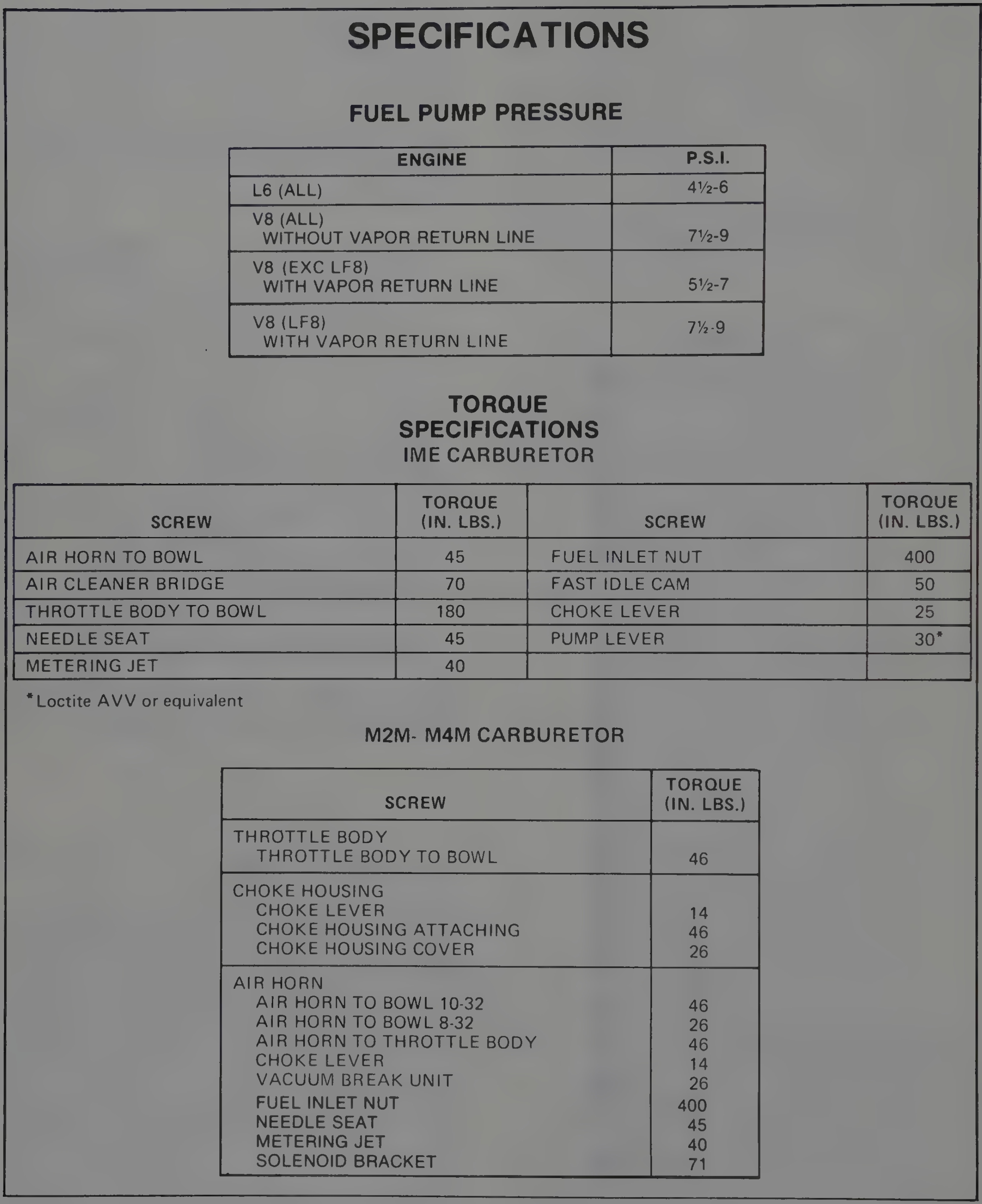

NOTE: RECHECK FAST IDLE ADJUSTMENT ON THE VEHICLE SETTING TO SPECIFICATIONS
①
HOLD CAM FOLLOWER ON HIGHEST STEP OF FAST IDLE CAM
②
TURN FAST IDLE SCREW OUT UNTIL PRIMARY THROTTLE VALVES ARE CLOSED
③
TURN SCREW IN TO CONTACT LEVER THEN TURN SCREW IN SPECIFIED NUMBER OF TURNS (NOTE)
FAST IDLE ADJUSTMENT (BENCH SETTING)

Figure 5-9. Repair procedures are often provided with numbered steps to follow. (Courtesy of Chevrolet Motor Division, General Motors Corporation)

Specification Charts

Specifications are usually found at the end of each section in charts. The **specification charts** shown in Figure 5-10 provide fuel pump pressure and torque specifications for the carburetor. To use the chart, look down the list for the information required. For example, to find the fuel pump pressure for a V-8 engine without a vapor return line, look down the column headed "ENGINE" to find the correct engine. Then read to the right to find the pressure, which is 7½-9 PSI (pounds per square inch).

NOTE: Use a rule or piece of paper as a guide to read across the chart. It is always best to write the specification down. Do not rely on memory or you could make an error!



SPECIFICATIONS

FUEL PUMP PRESSURE

ENGINE	P.S.I.
L6 (ALL)	4½-6
V8 (ALL) WITHOUT VAPOR RETURN LINE	7½-9
V8 (EXC LF8) WITH VAPOR RETURN LINE	5½-7
V8 (LF8) WITH VAPOR RETURN LINE	7½-9

TORQUE SPECIFICATIONS

IME CARBURETOR

SCREW	TORQUE (IN. LBS.)	SCREW	TORQUE (IN. LBS.)
AIR HORN TO BOWL	45	FUEL INLET NUT	400
AIR CLEANER BRIDGE	70	FAST IDLE CAM	50
THROTTLE BODY TO BOWL	180	CHOKE LEVER	25
NEEDLE SEAT	45	PUMP LEVER	30*
METERING JET	40		

*Loctite AVV or equivalent

M2M- M4M CARBURETOR

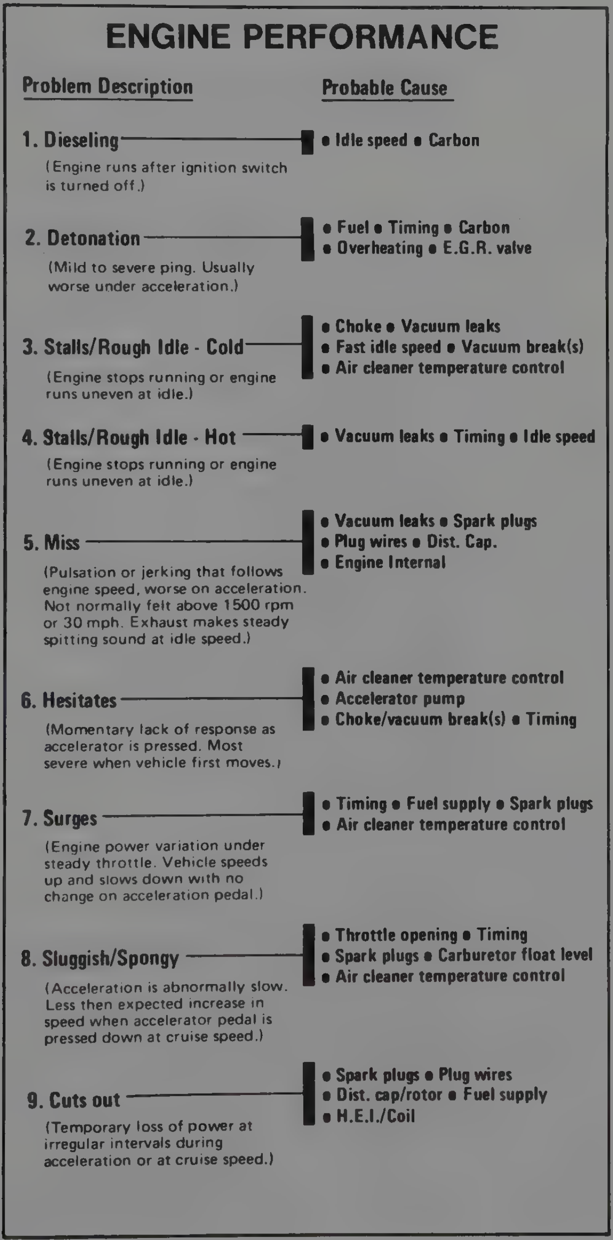
SCREW	TORQUE (IN. LBS.)
THROTTLE BODY THROTTLE BODY TO BOWL	 46
CHOKE HOUSING CHOKE LEVER CHOKE HOUSING ATTACHING CHOKE HOUSING COVER	 14 46 26
AIR HORN AIR HORN TO BOWL 10-32 AIR HORN TO BOWL 8-32 AIR HORN TO THROTTLE BODY CHOKE LEVER VACUUM BREAK UNIT FUEL INLET NUT NEEDLE SEAT METERING JET SOLENOID BRACKET	 46 26 46 14 26 400 45 40 71

Figure 5-10. Typical specification charts. (Courtesy of Chevrolet Motor Division, General Motors Corporation)

Troubleshooting Charts

Among the most valuable information provided by a service manual or repair manual are the **troubleshooting charts.** These charts, also called *guides*, are designed to help the technician save time in identifying and solving problems. They list common problems and probable causes for the problems.

One type of troubleshooting chart is shown in Figure 5-11. Descriptions of problems are listed in the left column and probable causes in the right column. For example, if the engine of a vehicle hesitates (Number 6 on the chart), the probable cause is the air cleaner temperature control, the accelerator pump, the choke/vacuum break(s), or the timing, so these are the areas that should be checked.



ENGINE PERFORMANCE

Problem Description	Probable Cause
1. Dieseling (Engine runs after ignition switch is turned off.)	• Idle speed • Carbon
2. Detonation (Mild to severe ping. Usually worse under acceleration.)	• Fuel • Timing • Carbon • Overheating • E.G.R. valve
3. Stalls/Rough Idle - Cold (Engine stops running or engine runs uneven at idle.)	• Choke • Vacuum leaks • Fast idle speed • Vacuum break(s) • Air cleaner temperature control
4. Stalls/Rough Idle - Hot (Engine stops running or engine runs uneven at idle.)	• Vacuum leaks • Timing • Idle speed
5. Miss (Pulsation or jerking that follows engine speed, worse on acceleration. Not normally felt above 1500 rpm or 30 mph. Exhaust makes steady spitting sound at idle speed.)	• Vacuum leaks • Spark plugs • Plug wires • Dist. Cap. • Engine Internal
6. Hesitates (Momentary lack of response as accelerator is pressed. Most severe when vehicle first moves.)	• Air cleaner temperature control • Accelerator pump • Choke/vacuum break(s) • Timing
7. Surges (Engine power variation under steady throttle. Vehicle speeds up and slows down with no change on acceleration pedal.)	• Timing • Fuel supply • Spark plugs • Air cleaner temperature control
8. Sluggish/Spongy (Acceleration is abnormally slow. Less then expected increase in speed when accelerator pedal is pressed down at cruise speed.)	• Throttle opening • Timing • Spark plugs • Carburetor float level • Air cleaner temperature control
9. Cuts out (Temporary loss of power at irregular intervals during acceleration or at cruise speed.)	• Spark plugs • Plug wires • Dist. cap/rotor • Fuel supply • H.E.I./Coil

Figure 5-11. Troubleshooting chart, also called a diagnosis chart. (Courtesy of Chevrolet Motor Division, General Motors Corporation)

The "road map" type of troubleshooting chart is shown in Figure 5-12. With this type of chart, the technician follows a set of procedures the way a person would follow a highway according to a road map. First, the troubleshooting chart for the appropriate problem is selected. The chart in Figure 5-12, for example, is headed "ENGINE CRANKS, BUT WILL NOT START." The technician begins reading at the top of the chart, then follows the lines on the chart downward. Depending on the results of each step, two or more possible courses of action may be presented. On the chart in Figure 5-12, two different procedures follow the first step — one in the event that a spark is observed, and one in the event that no spark is observed. The directions on this type of chart should be followed exactly, without skipping any steps.

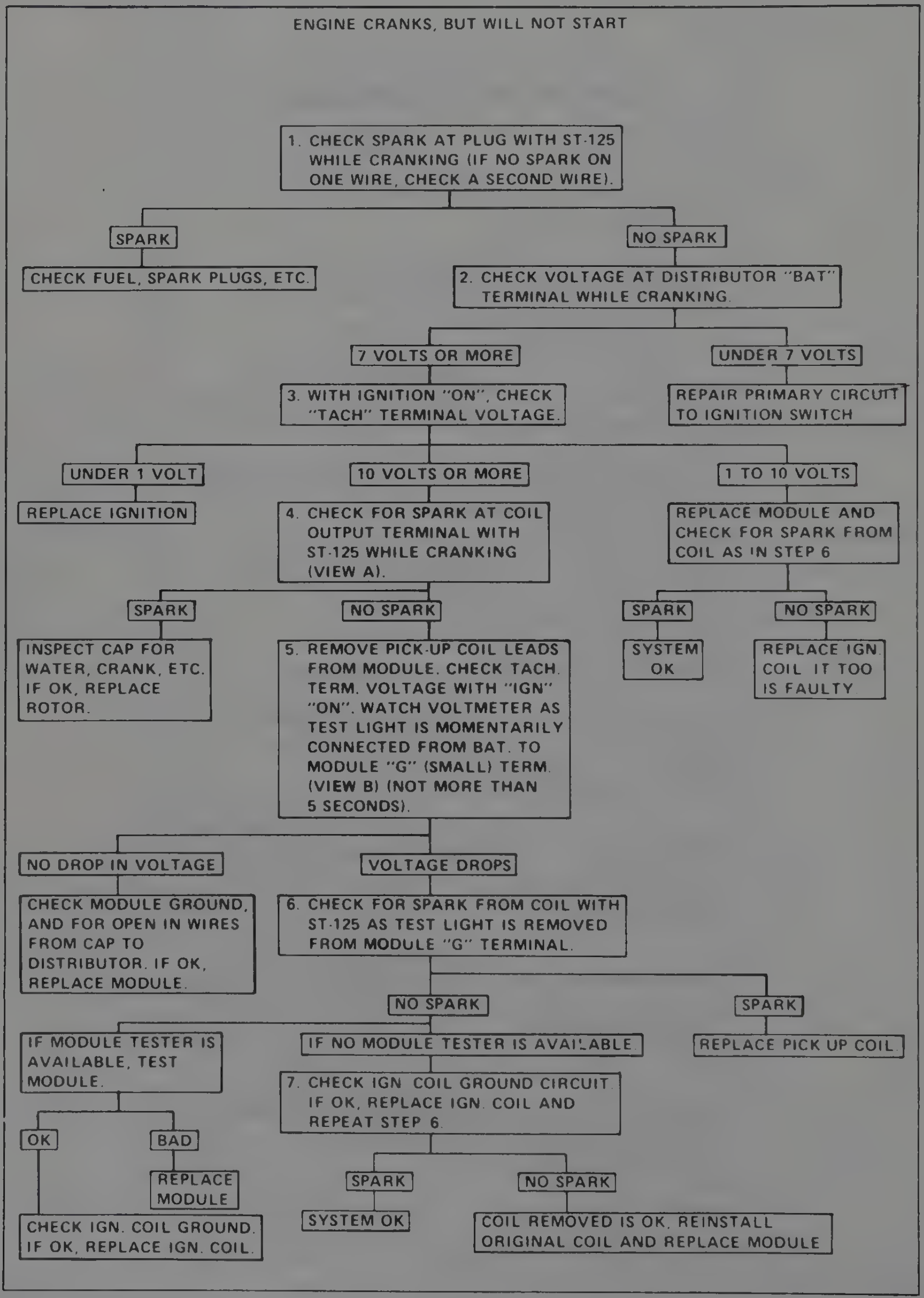

ENGINE CRANKS, BUT WILL NOT START
1. CHECK SPARK AT PLUG WITH ST-125 WHILE CRANKING (IF NO SPARK ON ONE WIRE, CHECK A SECOND WIRE).
SPARK
CHECK FUEL, SPARK PLUGS, ETC.
NO SPARK
2. CHECK VOLTAGE AT DISTRIBUTOR "BAT" TERMINAL WHILE CRANKING.
7 VOLTS OR MORE
UNDER 7 VOLTS
3. WITH IGNITION "ON", CHECK "TACH" TERMINAL VOLTAGE.
REPAIR PRIMARY CIRCUIT TO IGNITION SWITCH
UNDER 1 VOLT
REPLACE IGNITION
10 VOLTS OR MORE
4. CHECK FOR SPARK AT COIL OUTPUT TERMINAL WITH ST-125 WHILE CRANKING (VIEW A).
1 TO 10 VOLTS
REPLACE MODULE AND CHECK FOR SPARK FROM COIL AS IN STEP 6
SPARK
INSPECT CAP FOR WATER, CRANK, ETC. IF OK, REPLACE ROTOR.
NO SPARK
5. REMOVE PICK-UP COIL LEADS FROM MODULE. CHECK TACH. TERM. VOLTAGE WITH "IGN" "ON". WATCH VOLTMETER AS TEST LIGHT IS MOMENTARILY CONNECTED FROM BAT. TO MODULE "G" (SMALL) TERM. (VIEW B) (NOT MORE THAN 5 SECONDS).
SPARK
SYSTEM OK
NO SPARK
REPLACE IGN. COIL. IT TOO IS FAULTY.
NO DROP IN VOLTAGE
CHECK MODULE GROUND, AND FOR OPEN IN WIRES FROM CAP TO DISTRIBUTOR. IF OK, REPLACE MODULE.
VOLTAGE DROPS
6. CHECK FOR SPARK FROM COIL WITH ST-125 AS TEST LIGHT IS REMOVED FROM MODULE "G" TERMINAL.
NO SPARK
IF MODULE TESTER IS AVAILABLE, TEST MODULE.
IF NO MODULE TESTER IS AVAILABLE
SPARK
REPLACE PICK UP COIL
OK
BAD
REPLACE MODULE
CHECK IGN. COIL GROUND. IF OK, REPLACE IGN. COIL.
7. CHECK IGN. COIL GROUND CIRCUIT. IF OK, REPLACE IGN. COIL AND REPEAT STEP 6.
SPARK
SYSTEM OK
NO SPARK
COIL REMOVED IS OK. REINSTALL ORIGINAL COIL AND REPLACE MODULE

Figure 5-12. Typical "road map" type of troubleshooting chart. (Courtesy of Chevrolet Motor Division, General Motors Corporation)

Some manufacturers have developed diagnosis charts that use symbols, called **graphic mode symbols**. These symbols (road sign type illustrations) speed up diagnosis because the technician can see at a glance exactly what to do, rather than reading directions. Examples of graphic mode symbols are shown in Figure 5-13.

An example of a graphic mode diagnosis chart for a dieseling problem (engine keeps running after ignition is turned off) is shown in Figure 5-14. On this type of chart, start with the first step and follow the sequence from left to right. Each sequence ends with a check to see whether the problem has been corrected ("OK" or "Not OK"). If a problem has not been corrected, you are told the next step to take. Work through each step in the chart until the problem is corrected ("OK").

If following the chart does not solve the problem, repeat the procedures to be sure they were correctly followed. If the problem persists, it may be more complicated than that covered by the chart. In that case, you should check the latest specifications for the vehicle in the service manual.

Remember, troubleshooting charts are intended to cover problems that occur most frequently. They cannot cover every possible problem.

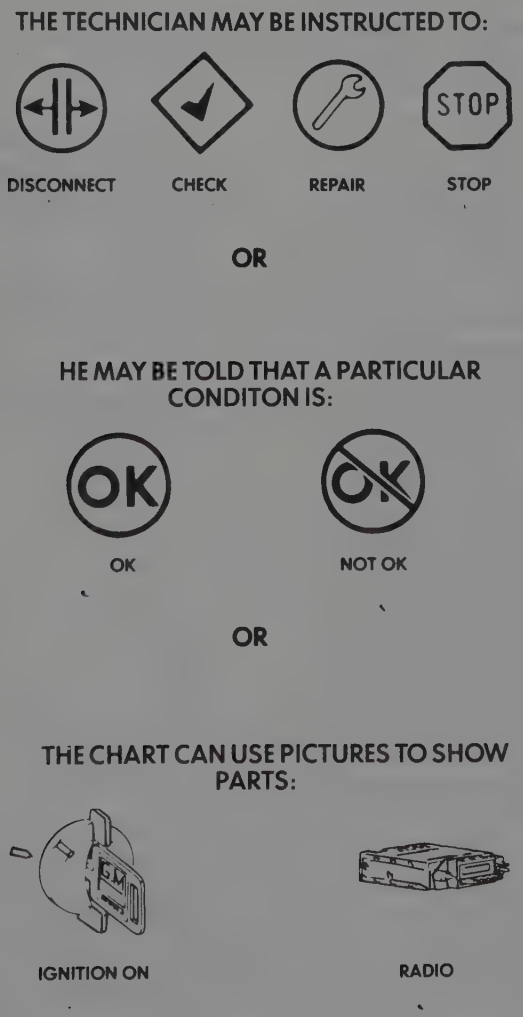

THE TECHNICIAN MAY BE INSTRUCTED TO:
STOP
DISCONNECT
CHECK
REPAIR
STOP
OR
HE MAY BE TOLD THAT A PARTICULAR CONDITON IS:
OK
OK
OK
NOT OK
OR
THE CHART CAN USE PICTURES TO SHOW PARTS:
GM
IGNITION ON
RADIO

Figure 5-13. Examples of graphic mode symbols and how they are used. (Courtesy of Chevrolet Motor Division, General Motors Corporation)

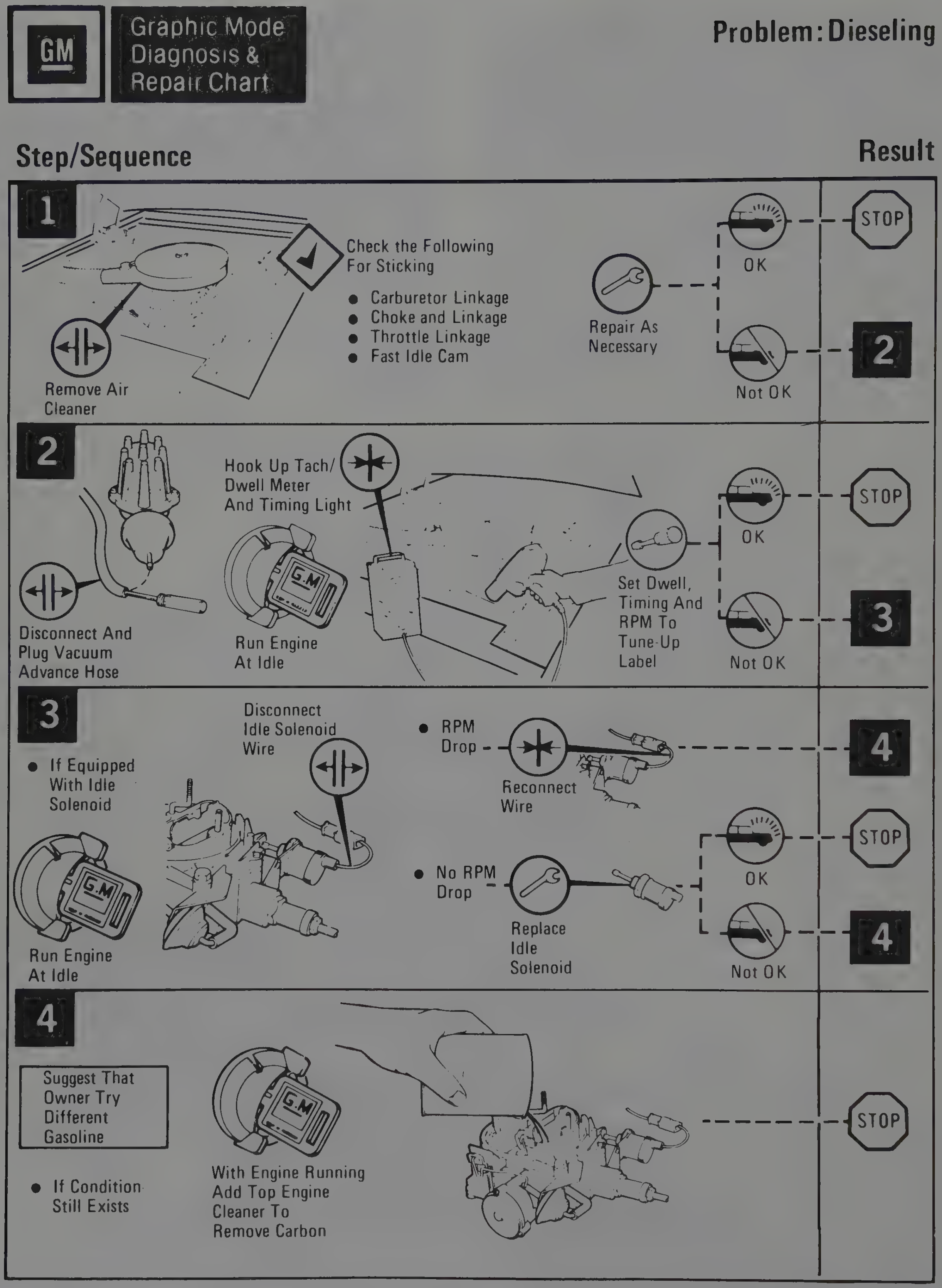

GM
Graphic Mode Diagnosis & Repair Chart
Problem: Dieseling
Step/Sequence
Result
1
Remove Air Cleaner
Check the Following For Sticking
● Carburetor Linkage
● Choke and Linkage
● Throttle Linkage
● Fast Idle Cam
Repair As Necessary
OK
STOP
Not OK
2
2
Disconnect And Plug Vacuum Advance Hose
Hook Up Tach/ Dwell Meter And Timing Light
G.M
Run Engine At Idle
Set Dwell, Timing And RPM To Tune-Up Label
OK
STOP
Not OK
3
3
● If Equipped With Idle Solenoid
Disconnect Idle Solenoid Wire
G.M
Run Engine At Idle
● RPM Drop
Reconnect Wire
4
● No RPM Drop
Replace Idle Solenoid
OK
STOP
Not OK
4
4
Suggest That Owner Try Different Gasoline
● If Condition Still Exists
G.M
With Engine Running Add Top Engine Cleaner To Remove Carbon
STOP

Figure 5-14. Graphic mode diagnosis chart. (Courtesy of Chevrolet Motor Division, General Motors Corporation)

KEY TERMS

General Repair Manual: A manual of repair procedures and specifications for vehicles of several years and models.

Graphic mode symbol: Road sign type symbols that allow the technician to see at a glance (rather than read) exactly what to do.

Service bulletin: A manufacturer's one-page or two-page description of a particular service problem and its corrective procedure that is sent to dealerships.

Service labels: A source for obtaining tune-up specifications, usually found under the hood of the vehicle.

Service (shop) manual: A manufacturer's manual providing repair procedures and specifications for a particular year and model of a vehicle.

Step-by-step repair techniques: An explanation in a service (shop) manual of how to disassemble, repair, reassemble, and adjust components.

Troubleshooting chart: A chart listing vehicle problems and most probable causes for the problems.

VIN: Abbreviation for vehicle identification number.

SELF-CHECK

1. Define specifications.
2. Where can tune-up specifications be found?
3. What information is found on an under-the-hood emission control information label?
4. What information does a general repair manual contain?
5. What information does a manufacturer's service (shop) manual contain?
6. How can engine type be determined?
7. Where is the VIN plate located?
8. Explain how to find specifications in a service manual.
9. Explain how to follow a "road map" type of troubleshooting chart.
10. How does a graphic mode diagnosis chart differ from other diagnosis charts?

DISCUSSION TOPICS AND ACTIVITIES

1. Look up a repair procedure in a general repair manual and in a service (shop) manual. How do the procedures differ?
2. Use a service manual to look up all the specifications for a tune-up.

CERTIFICATION PRACTICE

1. Recommended car manufacturer measurements for components are called:
   A. Dimensions
   B. Tolerances
   C. Specifications
   D. None of the above
2. Tune-up specifications can be found:
   A. On a service label
   B. In a general repair manual
   C. In a service manual
   D. All of the above
3. At a dealership, the most up-to-date information can usually be found in a:
   A. General repair manual
   B. Service manual
   C. Service bulletin
   D. None of the above
4. The VIN plate on a vehicle is:
   A. The vehicle identification number
   B. Located on the instrument panel
   C. Both A and B
   D. Neither A nor B
5. Which of the following is a type of troubleshooting chart?
   A. Diagnosis chart
   B. "Road map" chart
   C. Graphic mode diagnosis chart
   D. All of the above

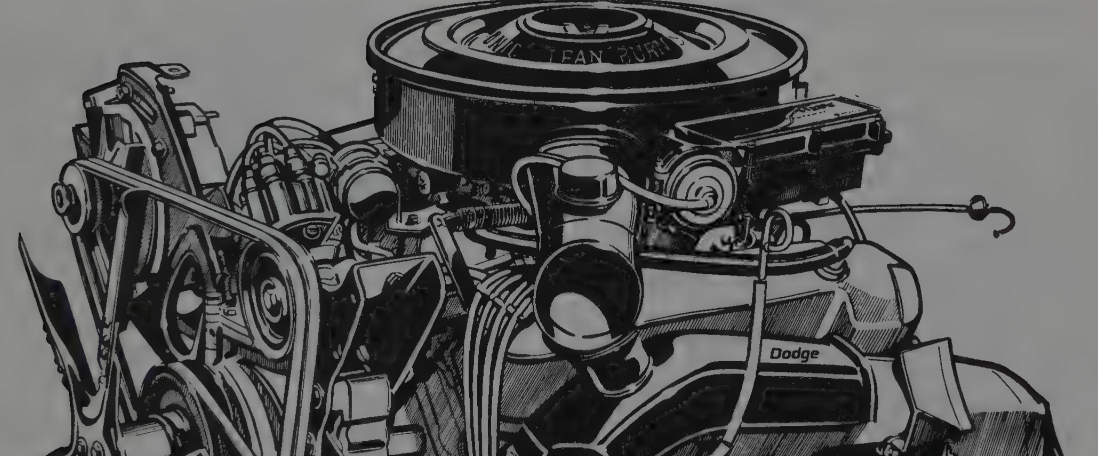
ANSWERS

1: C, 2: D, 3: C, 4: C, 5: D

SECTION II

Basic Engine Operation and Troubleshooting

Unit 6. Basic Engine Operation
Unit 7. Troubleshooting Engine Condition



Courtesy of Chrysler Corporation

Unit 6 BASIC ENGINE OPERATION

A tuned engine is one that has all its related systems working together to provide maximum power, highest possible fuel mileage, and lowest possible level of emissions. In order to perform a tune-up, the tune-up technician must understand the operation of the engine and each of its systems.

DEVELOPING JOB COMPETENCIES

When you finish reading and studying this unit, you should be able to:

- Identify and explain the purpose of the basic parts and operation of an internal combustion engine.
- Describe the operation of a four-stroke-cycle engine.
- Describe the purpose of cylinder numbering and firing order.
- Identify and explain the purpose of each of the parts of a valve train.
- Describe the operation and parts of the lubrication and cooling systems.

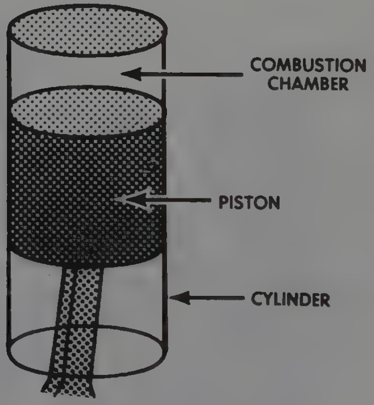


Figure 6-1. Basic parts of an internal combustion engine.

INTERNAL COMBUSTION ENGINE — BASIC PARTS AND OPERATION

Because combustion takes place inside the engine, the engine is called an **internal combustion engine**. In essence, it is a container in which air and fuel are burned to produce power (energy), converting heat energy into a usable form of mechanical energy. The area inside the engine used for burning air and fuel is called a **cylinder** (Figure 6-1). Inside the cylinder is a **piston**. The space between the piston and the top of the cylinder is called the **combustion chamber**. This is where the burning of the fuel and air takes place.

As the piston moves up in the cylinder, the gasoline (fuel) and air in the combustion chamber is squeezed tightly. When the mixture of gasoline and air (*air-fuel mixture*) is squeezed as tightly as possible, it is ignited by an electric spark and burned. The burning process, called *combustion*, increases the pressure inside the combustion chamber. This pushes the piston down the cylinder with great force as shown in Figure 6-2.

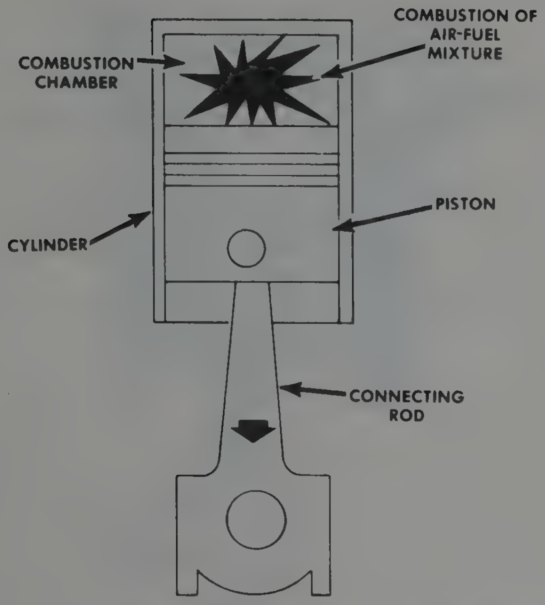

COMBUSTION OF AIR-FUEL MIXTURE
COMBUSTION CHAMBER
PISTON
CYLINDER
CONNECTING ROD

Figure 6-2. The force of combustion pushes the piston down the cylinder.

To use the power developed by the downward-moving piston, the piston is connected to a rod called a **connecting rod** (Figure 6-3). The lower end of the connecting rod is connected to the **crankshaft**. The upper end of the connecting rod is connected to the piston through a *piston pin* or *wrist pin*. This lets the connecting rod follow the crankshaft's motion. The downward movement of the connecting rod is changed to circular movement at the crankshaft. The crankshaft is mounted so that it can turn freely and is *offset* in the middle. This offset part is called a *throw* or *journal*.

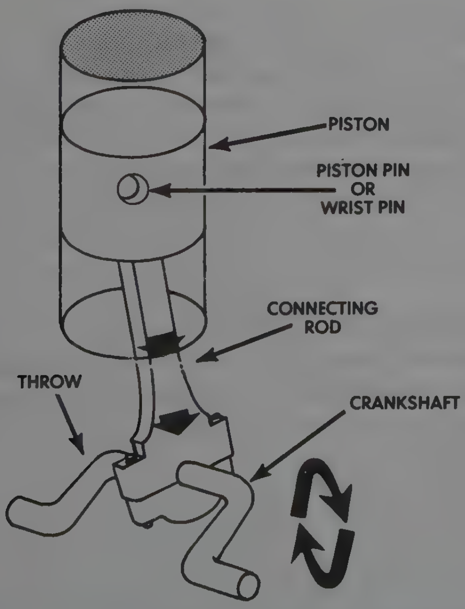

PISTON
PISTON PIN OR WRIST PIN
CONNECTING ROD
THROW
CRANKSHAFT

Figure 6-3. The connecting rod and crankshaft change the piston's downward motion to a circular motion.

To complete the basic engine, the piston must return to the top of the cylinder. This is necessary because the piston must be pushed down the cylinder more than one time. To accomplish this, a heavy wheel called a **flywheel** is mounted to the end of the crankshaft as shown in Figure 6-4. When the piston is forced down, the crankshaft will go around (revolve), and so will the flywheel. The weight of the moving flywheel keeps the crankshaft turning. This movement causes the piston to go back up to the top of the cylinder. The process can then repeat itself.

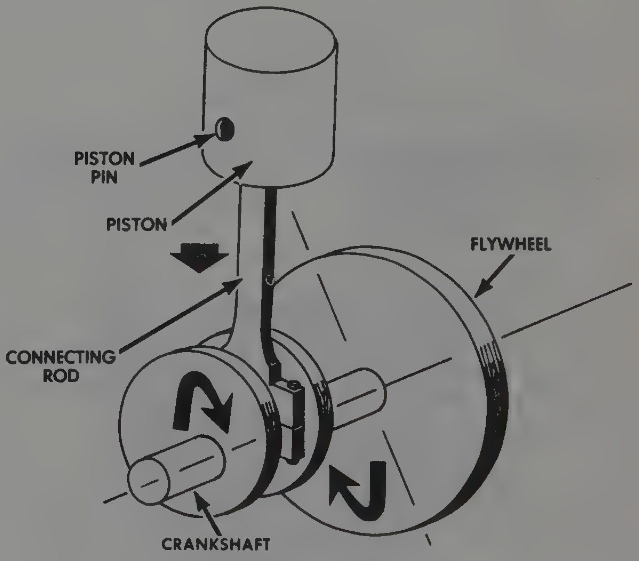

PISTON PIN
PISTON
FLYWHEEL
CONNECTING ROD
CRANKSHAFT

Figure 6-4. The flywheel is mounted on the end of the crankshaft.

THE FOUR-STROKE-CYCLE PRINCIPLE

Automobiles develop power in a series of events known as the **four-stroke cycle**. A *cycle* is one complete series of events that is constantly repeated. When the piston moves from the top of the cylinder, called *top dead center* (abbreviated **TDC**) to the bottom of the cylinder, called *bottom dead center* (abbreviated **BDC**), one stroke has occurred (Figure 6-5). When the piston moves BDC to TDC, another stroke has occurred. A series of four strokes is needed to develop power in the four-stroke-cycle engine.

The top of the cylinder has two holes that open and close. One allows the air-fuel mixture to enter the combustion chamber. It is called the *intake port*. The other allows the exhaust gases left after combustion to leave the chamber. It is called the *exhaust port*. The action that occurs during one complete cycle is as follows. (Both the intake and exhaust ports are closed at the beginning of a cycle, and the piston is as far up in the cylinder as the connecting rod will allow.)

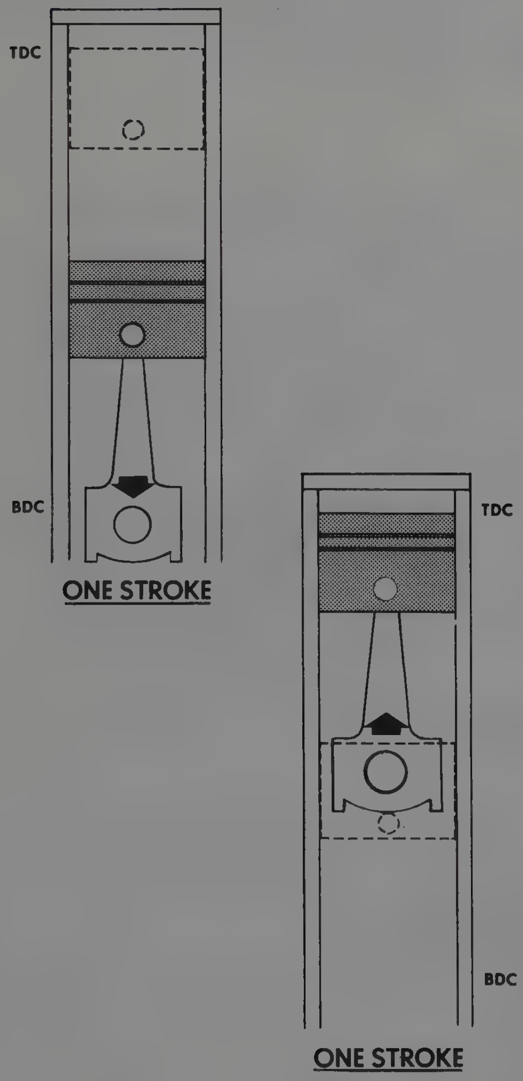
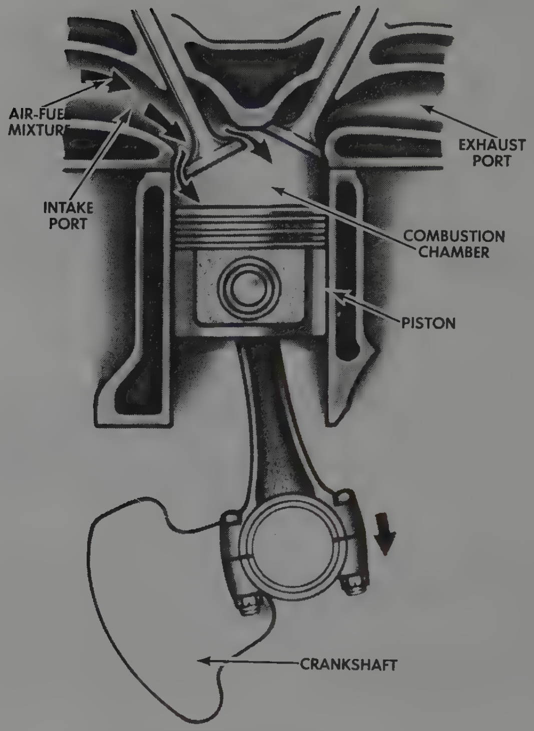


Figure 6-5. A stroke occurs when the piston moves from TDC to BDC or from BDC to TDC.



NOTE: THE SPARK PLUG IS NOT SHOWN BECAUSE IT WAS REMOVED WITH THE CUTAWAY SECTION.

Figure 6-6. The piston moves down, pulling the air-fuel mixture in on the intake stroke. (Courtesy of Chevrolet Motor Division, General Motors Corporation)

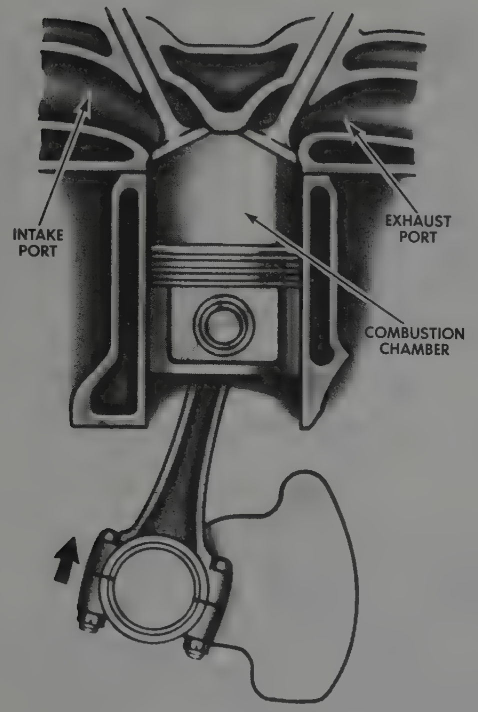
Intake Stroke

The **intake stroke** (Figure 6-6) begins with the piston moving down the cylinder. The rapid movement of the piston creates a low pressure area above the piston in the combustion chamber. The intake port above the piston opens, and the air-fuel mixture is forced into the cylinder. The piston has completed one stroke and the crankshaft has turned one-half turn, or 180°.

Compression Stroke

As the piston moves up for the **compression stroke**, the intake and exhaust ports are closed. The piston travels up as far as it can go, compressing, or squeezing, the air-fuel mixture in the combustion chamber (Figure 6-7).

As the piston moves upward, it compresses the air-fuel mixture into a space about one-eighth of its former volume. (See the discussion under the heading of "Compression Ratio" in this unit for more details.) The crankshaft has



NOTE: THE SPARK PLUG IS NOT SHOWN BECAUSE IT WAS REMOVED WITH THE CUT-AWAY SECTION

Figure 6-7. The piston moves up, squeezing the air-fuel mixture on the compression stroke. (Courtesy of Chevrolet Motor Division, General Motors Corporation)

turned another 180° and has completed one revolution (360°). The intake and exhaust ports remain closed.

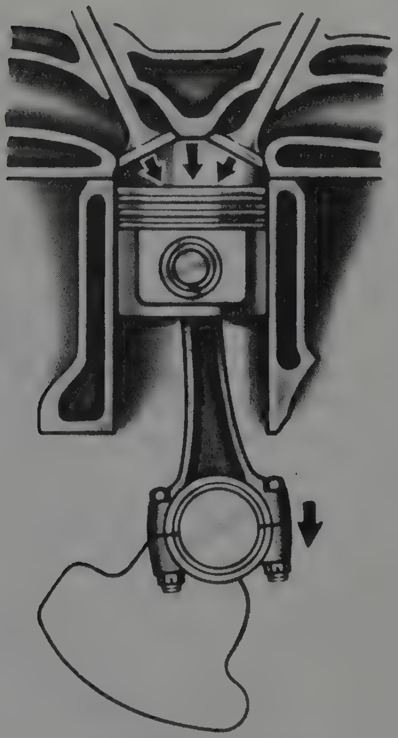
Power Stroke

As the piston nears the top of its travel on the compression stroke, a spark from the ignition system is used to ignite the air-fuel mixture. Once ignited, the fuel burns quickly and causes a rapid rise in pressure inside the cylinder. This increased pressure forces the piston down the cylinder for the **power stroke** (Figure 6-8), causing the crankshaft to rotate.

When the piston reaches the bottom of the cylinder, the power stroke is completed. The crankshaft turns still another 180° during this stroke.

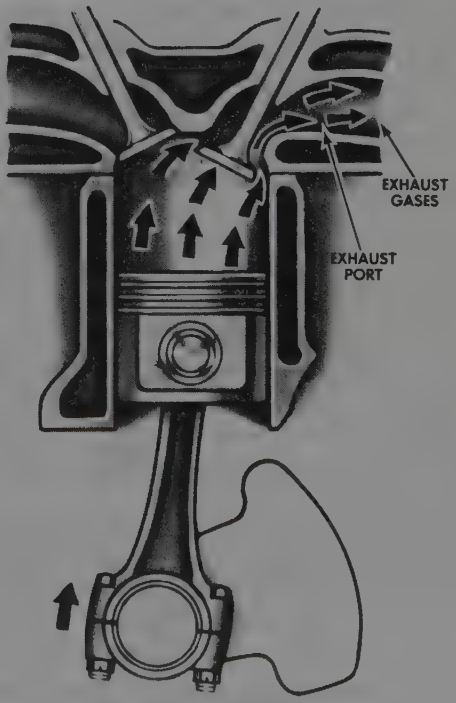
Exhaust Stroke

The **exhaust stroke** (Figure 6-9) begins as the piston once again starts to move upward in the cylinder. This time, however, the exhaust port is opened. *Exhaust gases* (also called *burned*



NOTE: THE SPARK PLUG IS NOT SHOWN BECAUSE IT WAS REMOVED WITH THE CUT-AWAY SECTION.

Figure 6-8. The air-fuel mixture is ignited, causing the combustion that forces the piston down on the power stroke. (Courtesy of Chevrolet Motor Division, General Motors Corporation)



NOTE: THE SPARK PLUG IS NOT SHOWN BECAUSE IT WAS REMOVED WITH THE CUT-AWAY SECTION.

Figure 6-9. Exhaust gases are forced out the exhaust port on the exhaust stroke. (Courtesy of Chevrolet Motor Division, General Motors Corporation)

gases) trapped in the cylinder after combustion are pushed out the exhaust port as the piston moves to TDC. This completes the final stroke of the four strokes.

To summarize the four-stroke-cycle principle:

- *Intake stroke:* The piston moves from the top of the cylinder to the bottom. The air-fuel mixture is pulled in through an open intake port.
- *Compression stroke:* The piston moves up, compressing the air-fuel mixture.
- *Power stroke:* A spark from the ignition system ignites the air-fuel mixture, causing a pressure rise inside the cylinder, and pushes the piston down.
- *Exhaust stroke:* The piston moves up, pushing exhaust gases out of the cylinder through an open exhaust port.

These four strokes make up one complete cycle. This cycle is repeated over and over to develop power. When the engine has completed one cycle, it is ready for another one. Each cycle requires four strokes of the piston and two revolutions of the crankshaft.

COMPRESSION RATIO

Compression ratio is related to the compression stroke of the four-stroke cycle. On this stroke, the piston moves up while both the intake and exhaust valves are closed. The piston squeezes the air-fuel mixture in the top of the cylinder. The tighter the mixture is squeezed, the higher the engine compression becomes. The higher the compression an engine has, the more power the engine can develop. The **compression ratio** is a measurement of the degree to which the air and fuel are compressed in the engine. We can find the compression ratio by measuring the volume of a cylinder as follows: First, we measure the volume when the piston is at BDC. Second, the piston is moved to TDC, and we measure the volume in the small area above the piston.

For example, in Figure 6-10, the piston on the left is at BDC. If we measure the volume, we find it is 8 cubic inches. The piston is then moved to TDC as shown on the right side of Figure 6-10. We find there is only 1 cubic inch of space now. This means 8 cubic inches of air-fuel mixture are squeezed into an area of 1 cubic inch. The result is a compression ratio of 8 to 1.

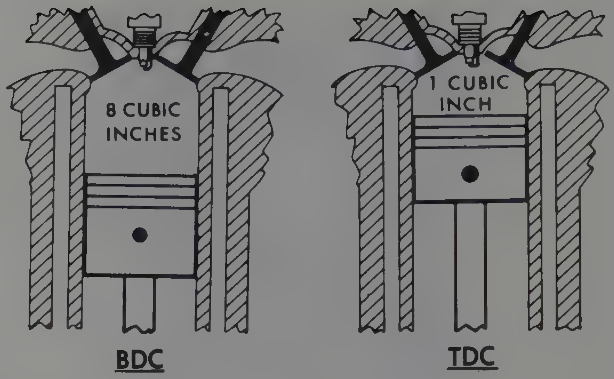


Figure 6-10. Compression ratio of 8 to 1.

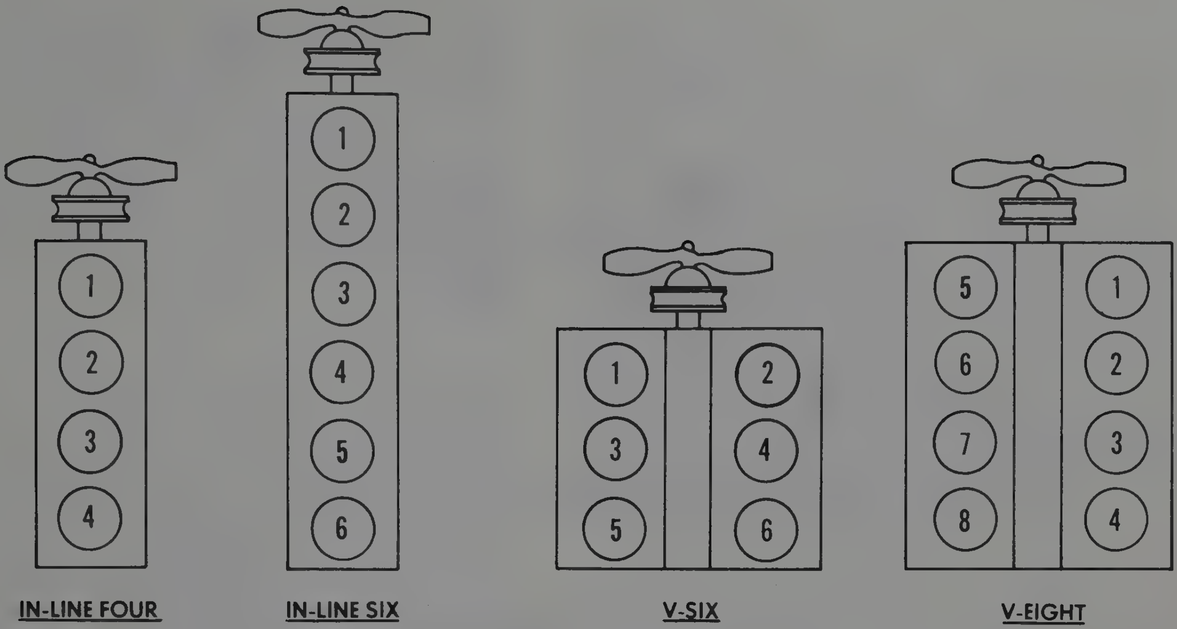
CYLINDER NUMBERING AND FIRING ORDER

In an engine with more than one cylinder, the same strokes occur in each cylinder. However, the crankshaft is designed so that at a given time, different strokes are occurring in each cylinder. In a *four-cylinder* engine, for example, while one piston is moving down on intake, another will be moving up on compression, another down on power, and another up on exhaust. Thus, a power stroke is always pushing on the crankshaft.

The ignition system is designed to deliver a high-voltage spark to each cylinder when its piston is ready for a power stroke. This is based upon the manufacturer's cylinder numbering system and firing order. Each manufacturer of a multiple-cylinder engine assigns a **cylinder number** to each cylinder of that engine. These numbers are used to identify the different cylinders. The numbering practice is fairly standard for *in-line* engines. The cylinders are numbered consecutively, starting at the front of the automobile. The numbering of the cylinders in a *V-type* engine, however, varies from one manufacturer to another. Typical cylinder numbering systems are shown in Figure 6-11.

The **firing order** is the sequence in which each cylinder receives a spark and delivers a power stroke. The firing order is based upon the design of the crankshaft, which in turn determines which piston is at TDC and ready for a power stroke. Firing order is designed to make the engine run as smoothly as possible.

The angle between the throws (offset parts of the crankshaft) determines when each piston is ready for a power stroke. The crankshaft for



IN-LINE FOUR

IN-LINE SIX

V-SIX

V-EIGHT

Figure 6-11. Typical cylinder numbering systems.

an in-line, four-cylinder engine is arranged with crankshaft throws, or journals, 180° apart (Figure 6-12). When the No. 1 piston moves down on a power stroke, the No. 4 piston is moving down on intake. At the same time, the No. 2 and No. 3 pistons are moving up (one on exhaust and the other on compression). The order in which the pistons have a power stroke (firing order) is 1, 2, 4, 3 or 1, 3, 4, 2.

An engine with more than four cylinders provides more power strokes-per-crankshaft revolution. This means that there can be an overlapping of power strokes, called **power overlap**, resulting in a smoother running engine. For example, the in-line six-cylinder engine has its crankshaft throws spaced 120° apart (Figure 6-13). The cylinders provide a power pulse every one-third revolution of the crankshaft. This helps to eliminate any undue stress on any one part of the crankshaft by spreading the power strokes over its entire length. When an end cylinder (No. 1 or No. 6) fires, the next cylinder to fire is in the middle or toward the other end of the crankshaft. Most engines are designed so that the *two cylinders next to each other will not fire close together.* Two common firing orders used with six-cylinder, inline engines are: 1, 5, 3, 6, 2, 4 and 1, 4, 2, 6, 3, 5.

V-type engine firing orders are designed to alternate firing between the ends of the crankshaft and each bank of cylinders. This allows the forces to be distributed over the entire engine rather than concentrating power pulses on any one area of the crankshaft. The angle of the crankshaft throws on a V-8 (V-type, eight-cylinder) engine is 90° (Figure 6-14). Common V-8 firing orders are: 1, 8, 4, 3, 6, 5, 7, 2; 1, 6, 2, 5, 8, 3, 7, 4; 1, 5, 4, 2, 6, 3, 7, 8; and 1, 8, 7, 3, 6, 5, 4, 2.

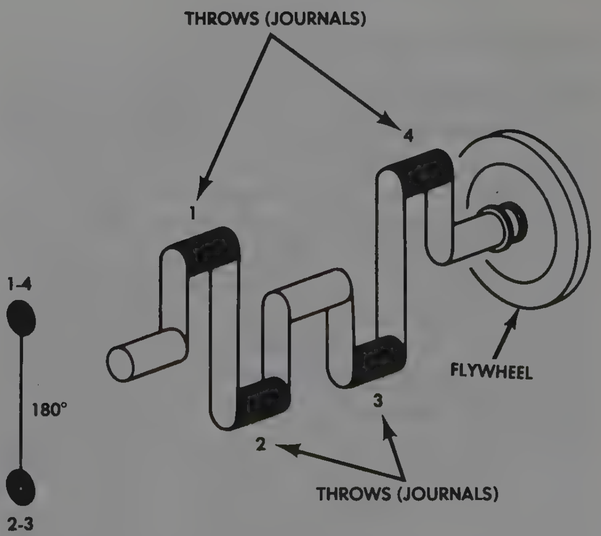


Figure 6-12. The crankshaft throws for an in-line, four-cylinder engine are 180° apart.

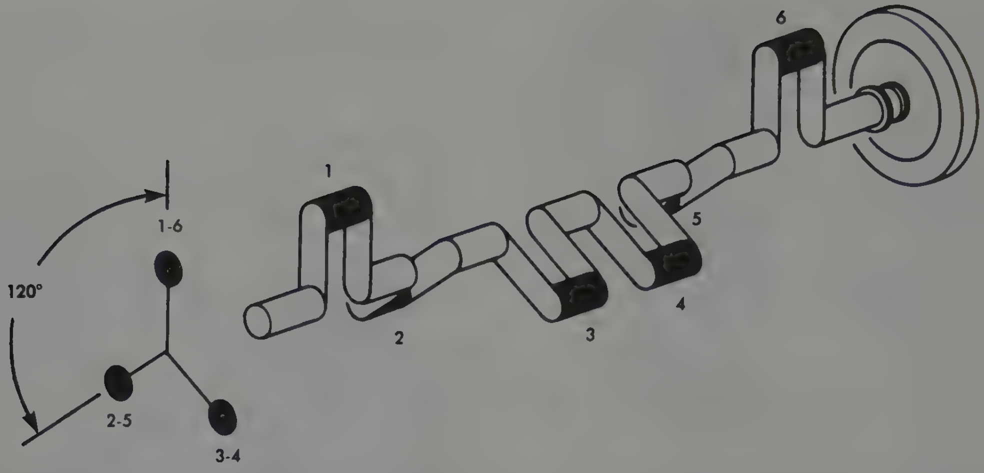


Figure 6-13. The crankshaft throws for an in-line, six-cylinder engine are spaced 120° apart.

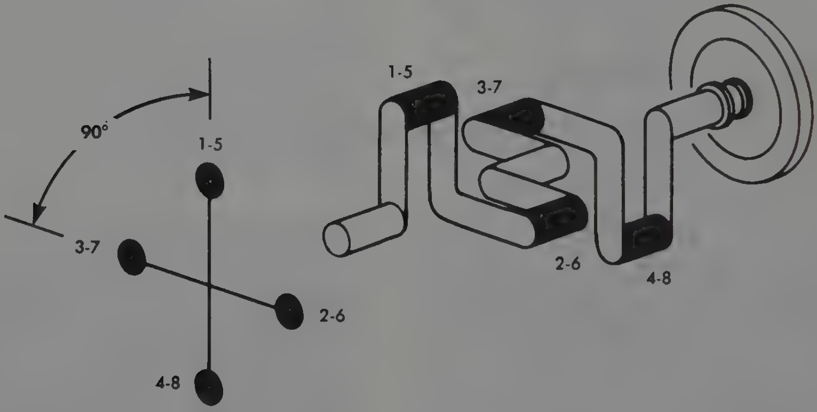


Figure 6-14. The crankshaft throws on this V-8 engine are spaced 90° apart.

VALVE TRAIN OPERATION

The four-stroke cycle depends upon the air-fuel mixture being admitted to the cylinder, being trapped there, and later being expelled as exhaust gases. All this requires two *passages (ports)*, which open and close by means of *valve assemblies* above the pistons. The mechanism that performs this function is the **valve train**.

The heart of the valve train is the *camshaft*, which is driven by the crankshaft (Figure 6-15). The camshaft has a number of eccentrics, or *cam lobes*, located along its length. As the crankshaft turns, the camshaft is driven at one-half crankshaft speed. Located above each cam lobe is a component called a *valve lifter* (also referred to as a *lifter* or *follower*). Rotation of the camshaft causes the high part of the cam lobe to push the lifter up. The lifter in turn pushes

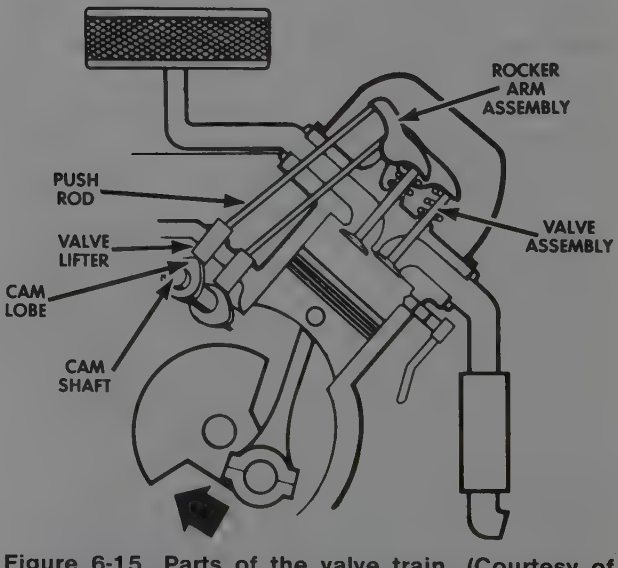


Figure 6-15. Parts of the valve train. (Courtesy of Oldsmobile Division, General Motors Corporation)

on a *push rod* that runs up along the outside of the cylinder. The push rod pushes on a *rocker arm*, also referred to as a *rocker arm assembly*. The rocker arm pushes down on the end of a valve assembly. This action opens the valve.

As the camshaft continues to turn, the low part of the cam lobe passes under the lifter. A strong spring called a *valve spring* or *coil spring* can now close the valve as shown in Figure 6-16. The valve spring is part of the valve assembly.

The rocker arm and valve assemblies are located in the *cylinder head* (Figure 6-16). The cylinder head is bolted to the top of the *cylinder block*. There are two valve assemblies above each piston. The valve assembly used to control the inlet of air and fuel is referred to as the *intake valve*. The other, known as the *exhaust valve*, controls the escape of exhaust gases. The valves have a precision-ground taper called a *face*, which matches a precision-ground *seat* in the cylinder head. The valve spring holds the valve on its seat for an airtight seal.

To summarize the action of the valves in the four-stroke cycle:

- *Intake Stroke:* The intake valve is pushed open while the exhaust valve is held closed. This allows the air-fuel mixture to enter.
- *Compression Stroke:* Both valves are held closed.
- *Power Stroke:* Both valves remain closed.
- *Exhaust Stroke:* The exhaust valve opens while the intake valve is held closed. This allows the exhaust gases to escape.

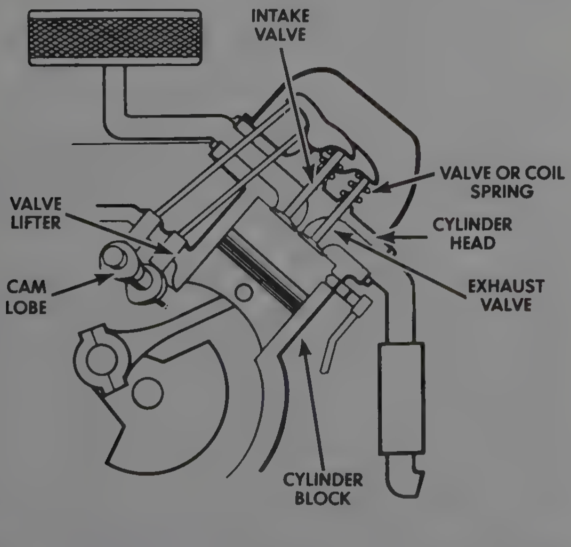


Figure 6-16. The valve springs, or coil springs, keep the valves seated for an airtight seal. (Courtesy of Oldsmobile Division, General Motors Corporation)

VALVE TIMING

The valves must open at just the right time during the four-stroke cycle. To time the valve opening to the piston strokes, the camshaft is driven by *gears* or *sprockets and chain* directly from the crankshaft. Since an open valve is needed only during two strokes (intake and exhaust), the camshaft needs to rotate at only one-half crankshaft speed. The gear or sprocket on the camshaft is twice as large as that on the crankshaft. This causes the camshaft to turn at one-half crankshaft speed. Timing marks on the two gears or sprockets are used to ensure that the camshaft and crankshaft are correctly synchronized. A timing chain and sprocket assembly are shown in Figure 6-17.

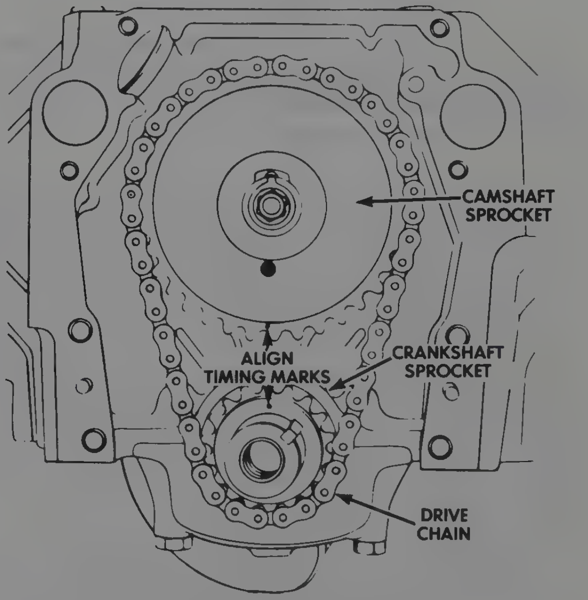


Figure 6-17. The camshaft is driven by the crankshaft at one-half crankshaft speed. (Courtesy of Cadillac Motor Car Division, General Motors Corporation)

The opening and closing of the valves in relation to crankshaft position is called *valve timing*. Valve timing for a typical engine is shown on the valve timing diagram in Figure 6-18. The intake valve begins to open before the piston reaches top dead center (TDC), and the exhaust valve remains open until after it reaches TDC. For a short period of time both valves are open. This period is called **valve overlap**. Valve overlap uses the inertia of the air-fuel mixture and exhaust gases (burned gases) to empty and fill the cylinder.

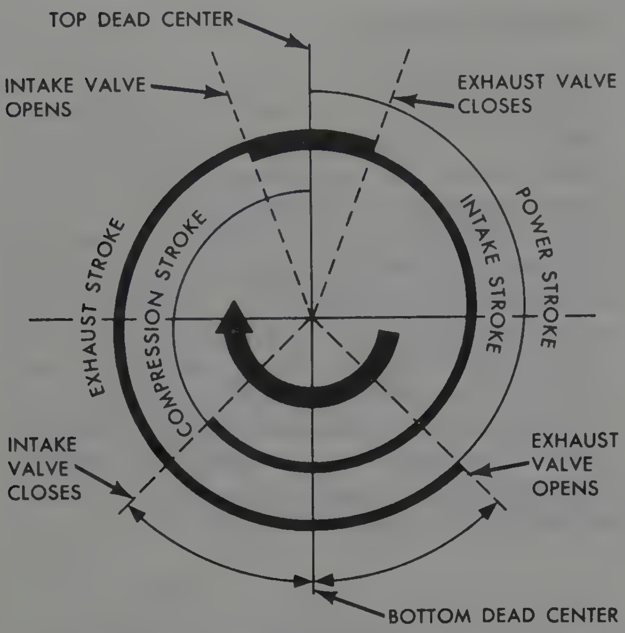


Figure 6-18. Valve timing diagram for a typical engine. (Courtesy of Chevrolet Motor Division, General Motors Corporation)

When the air-fuel mixture and exhaust gases move in or out of the cylinder, the weight of the mixture (or gases) creates momentum in the direction it is flowing. When a valve opens, the initial air flow is slow. Valve timing allows for this lag in starting and stopping in the flow. In order to pack the maximum air-fuel mixture into the cylinder, each valve opens earlier and closes later than would be necessary if the mixture were weightless.

To summarize valve overlap:

- *Intake Stroke:* The exhaust valve stays open a little after TDC is reached to take advantage of the momentum of the exhaust gases rushing out past the exhaust valve. With the exhaust valve still open, the cylinder continues to empty because of this momentum, even though the piston has started down.
- *Compression Stroke:* The intake valve stays open after bottom dead center (BDC) is reached. Incoming air-fuel mixture will continue to enter for a short time after the piston reverses direction (moves upward).
- *Power Stroke:* The exhaust valve opens before BDC is reached to start the exhaust gases out of the cylinder.
- *Exhaust Stroke:* The intake valve opens before TDC is reached to start the air-fuel mixture moving into the cylinder.

ENGINE SUPPORT SYSTEMS

To operate an engine, *ignition, fuel, emission control, lubrication,* and *cooling systems* are required. Later units discuss the operation, troubleshooting, and servicing of the ignition, fuel, and emission control systems. This unit discusses the lubrication and cooling systems, both of which are important parts of engine tune-up.

Lubrication System

The **lubrication system** provides (circulates) oil to engine parts for the purpose of lubrication. In **lubrication**, oil is forced between moving engine parts to prevent metal-to-metal contact that causes friction and wear. The circulating oil also carries heat away from engine parts, cleans engine parts, and helps the *piston rings* seal compression pressures.

All engine lubrication systems require a reservoir of oil. The **oil pan** attached to the bottom of the engine block provides space to store the lubricating oil (Figure 6-19).

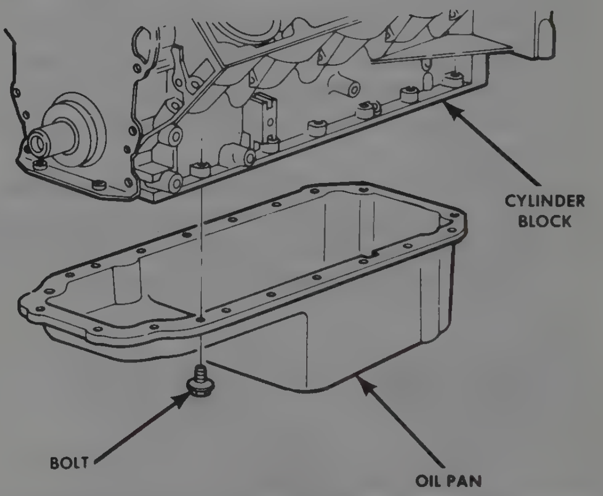


Figure 6-19. Oil for lubrication is stored in a reservoir called the oil pan. (Courtesy of Cadillac Motor Car Division, General Motors Corporation)

The oil pan may be stamped from steel or cast from aluminum. It is bolted to the bottom of the engine crankcase. The deep part of the oil pan houses an **oil pump**. The oil pan also collects oil that runs off engine parts after lubrication. A *plug* in the bottom of the oil pan is used to drain the oil at required intervals.

When the engine is running, oil is circulated throughout the engine by the oil pump (Figure 6-20). A typical oil pump has two small gears (*drive gear* and *idler gear*) which mesh with each other. The drive gear is attached to a *drive shaft*. The drive shaft is attached to a *drive shaft extension* from the engine camshaft. When the engine is running, the shaft turns and causes the drive gear in the *pump body* to turn. The idler gear in the pump body is mounted on a *stationary idler shaft*. Therefore, when the drive gear turns, the idler gear also turns.

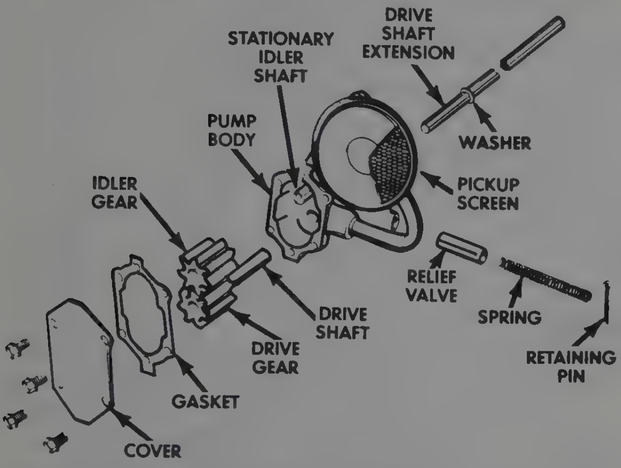


Figure 6-20. Exploded view of the oil pump used to circulate oil through the engine for lubrication. (Courtesy of Chevrolet Motor Division, General Motors Corporation)

As the two gears in the pump body turn, their teeth constantly mesh and unmesh. When the teeth unmesh, a low-pressure area is created between the teeth. A passage in the body allows oil to move into the pump to fill up the low-pressure area. Oil in the pump body is carried around in the teeth of the gears and forced out an outlet passage and into the block under pressure.

The pump body also includes a **relief valve**. The relief valve protects the lubrication system from excessive oil pressure. The valve is a small tube-shaped unit backed up with a calibrated *spring*. Oil from the pump outlet passes by the valve. As long as oil pressure is within safe limits, the relief valve and spring allow the oil to go out the outlet passage. If oil pressure becomes too high, the pressure pushes the relief valve back against the spring. As the valve moves back, a passage is uncovered from the pump body back into the oil pan. Opening a passage to the oil pan reduces the pressure. As soon as the pressure drops, the spring closes the relief valve.

While the engine is running, oil is picked up from the oil pan through the **pickup screen** in the oil pump (Figure 6-21). The pickup screen filters out large particles of dirt before they can enter the oil pump. The pump then routes the oil through an **oil filter** which cleans the oil before it enters the engine block to lubricate critical engine components. The oil filter is located on the outside of the cylinder block where it can be serviced. It spins onto a mount on the side of the engine block. The oil filter is an assembly that incorporates filtering material and a canister, usually constructed in one piece. When it is time to change the filter, the canister and filtering material are changed as a unit.

Treated paper is commonly used as the filtering material. As the oil passes through the treated paper, the dirt and acids in the oil stick to the outside of the paper — only the cleaned oil gets through.

A **bypass valve** is an assembly located in the oil filter or in the engine block where the filter is mounted. It protects the engine from a clogged filter by directing oil around the filter if it is clogged. As dirt accumulates on the filtering material, higher pressures are required to force the oil through the filter. A completely clogged filter could prevent oil from getting through and result in loss of lubrication and damage to the engine.

After the oil leaves the oil filter (Figure 6-21) it enters the passages, called **oil galleries**, in the cylinder block. Oil enters two *main galleries* that run the length of the block. The oil travels down from the main galleries to the crankshaft *main bearings*. As oil flows through the main bearings, it provides lubrication and then enters the hollow crankshaft. Then it flows through the crankshaft to lubricate each of the *connecting rod bearings*.

Oil flows down from the main gallery and through the block to the *camshaft bearings* and *camshaft bearing journal* and then to the *camshaft sprocket*. It is routed to each of the cam lobe areas and into each of the valve lifters. The oil flows through the lifters and up the hollow push rods. Finally, as oil exits the top of the push rods, it provides lubrication to the rocker arms and valve stems (the long rod-like part of the valves).

The rotating crankshaft throws off oil which hits the cylinder walls. The piston and *piston rings* receive oil and distribute it over the cylinder wall for lubrication. Then the oil runs back into the oil pan to be used again.

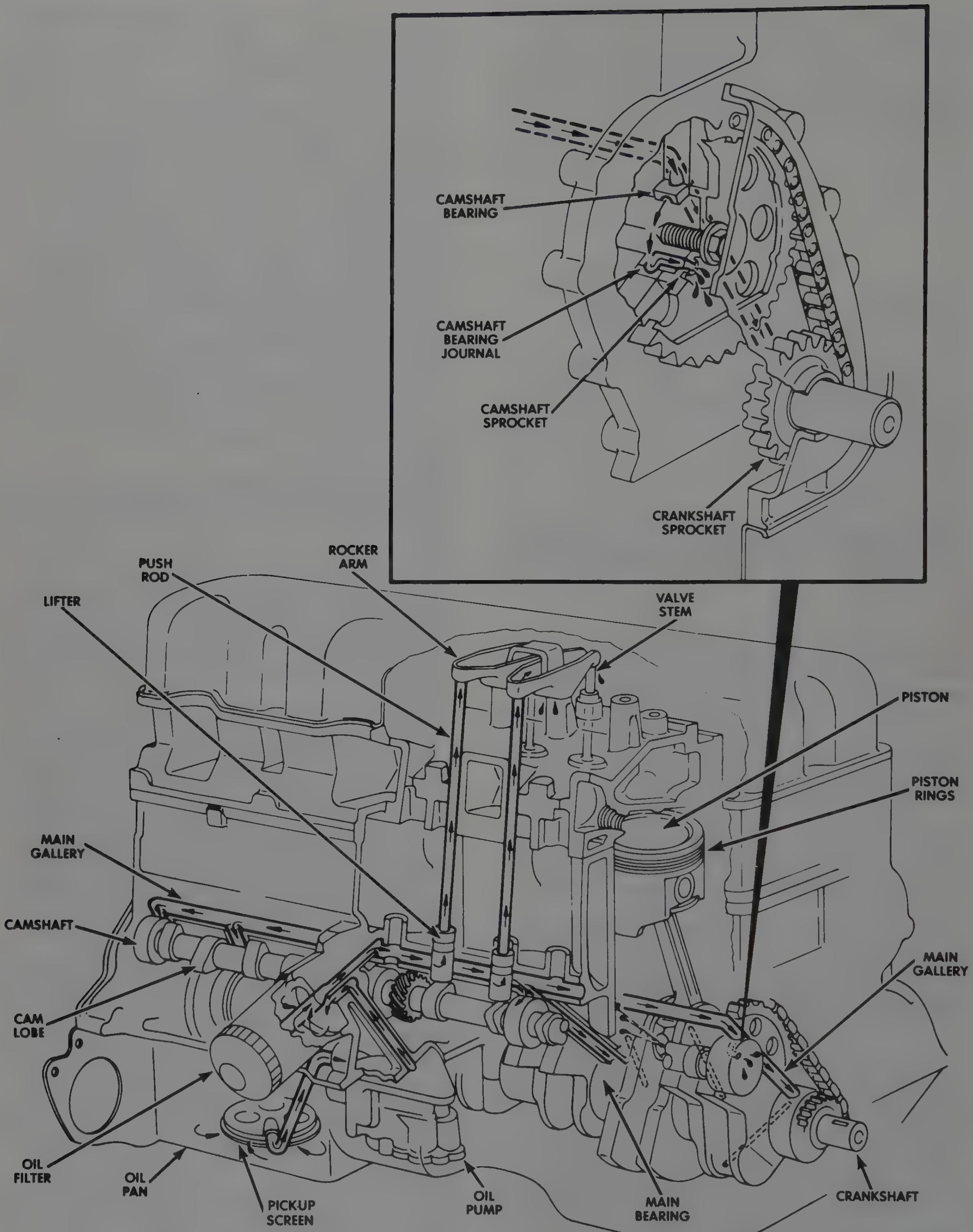

CAMSHAFT BEARING
CAMSHAFT BEARING JOURNAL
CAMSHAFT SPROCKET
CRANKSHAFT SPROCKET
ROCKER ARM
PUSH ROD
LIFTER
VALVE STEM
PISTON
PISTON RINGS
MAIN GALLERY
CAMSHAFT
CAM LOBE
MAIN GALLERY
OIL FILTER
OIL PAN
PICKUP SCREEN
OIL PUMP
MAIN BEARING
CRANKSHAFT

Figure 6-21. Circulation of oil (see arrows) through the lubrication system. (Courtesy of American Motors Corporation)

Cooling System

The engine power stroke develops a tremendous amount of heat. The heat must be controlled to prevent damage to engine parts. The **cooling system** regulates and controls engine heat, or temperature. Most automotive engines circulate liquid, referred to as **coolant**, around hot engine parts to remove heat.

Engines that are cooled by coolant have cooling passages, called **water jackets**, cast into the cylinder block and cylinder head (Figure 6-22). Each cylinder and valve seat in the block is surrounded by these passages. They are also arranged in the cylinder head very close to the valve area. While the engine is running, some of the heat from the burning air-fuel mixture passes through the metal of the cylinder head and cylinder wall and enters the water jackets. The heat is then transferred to the coolant circulating through the water jackets.

The cooling passages are called water jackets because originally water was used as a coolant. More sophisticated coolants have since been developed. Water formed rust in the water jackets, and the rust acted as a barrier against heat transfer. Rust also tended to scale off and interfere with coolant circulation throughout the system. Current practice is to use a mixture of *ethylene glycol* and water as the coolant.

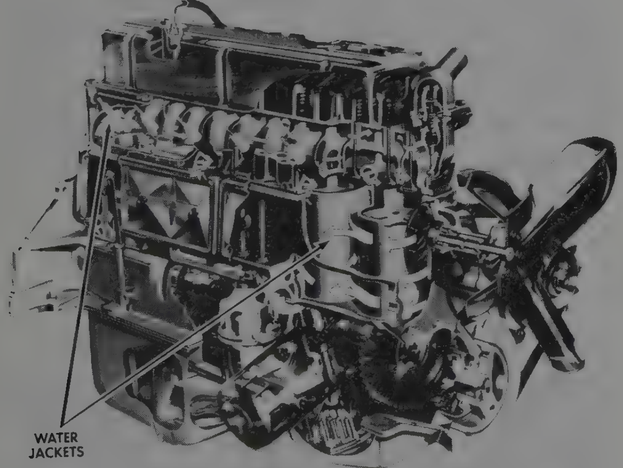


Figure 6-22. Areas that become hot in the engine are surrounded by water jackets, through which coolant flows (see white arrows). (Courtesy of Chevrolet Motor Division, General Motors Corporation)

Coolant is circulated through the water jackets of the engine by a **coolant pump**, also referred to as a *water pump*. A sectional view of a coolant pump is shown in Figure 6-23. The *pump body* of the coolant pump is bolted to the front of the engine. The water jackets of the engine are linked to the coolant pump. A gasket forms a seal between the coolant pump and engine. A small wheel with blades, called an *impeller*, is located in the center of the pump body. The impeller is mounted on a *shaft* which is supported by a *bearing*. A *seal* prevents coolant from entering the bearing. A *drive flange* at one end of the shaft provides a mount for a *pulley*. A *drive belt* (fan belt) connects the pulley to the crankshaft.

As the crankshaft turns, the drive belt turns the shaft and causes the impeller to spin. The shape of the blades on the impeller throws the coolant off the blades by centrifugal force. As the coolant leaves the blades, a low-pressure area is created in the coolant pump that pulls more coolant into the body. Coolant that leaves the blades goes out of the pump body and into the engine block.

Coolant that has been heated by the cylinders and valve assemblies must then be cooled. This is done by pumping the hot coolant out of the engine and through a large *heat exchanger* called a **radiator**. The purpose of the radiator is to transfer the heat of the coolant to the outside air.

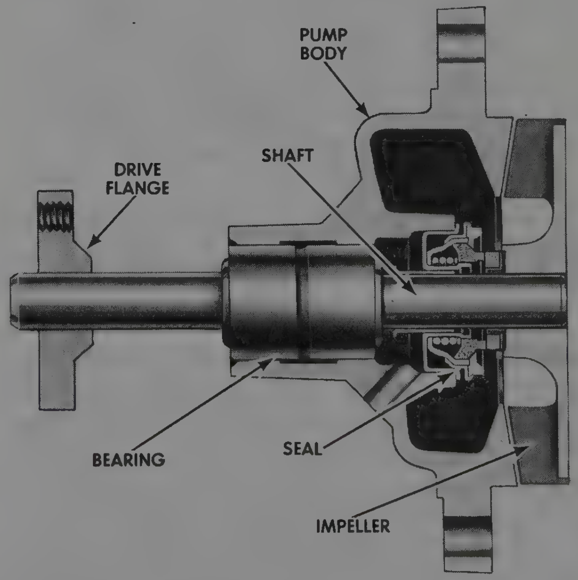


Figure 6-23. Sectional view of a coolant pump. (Courtesy of Chevrolet Motor Division, General Motors Corporation)

The radiator consists of a *top tank, bottom tank,* and a *center core* (Figure 6-24). The radiator is mounted in front of the engine compartment. The coolant pump circulates hot coolant

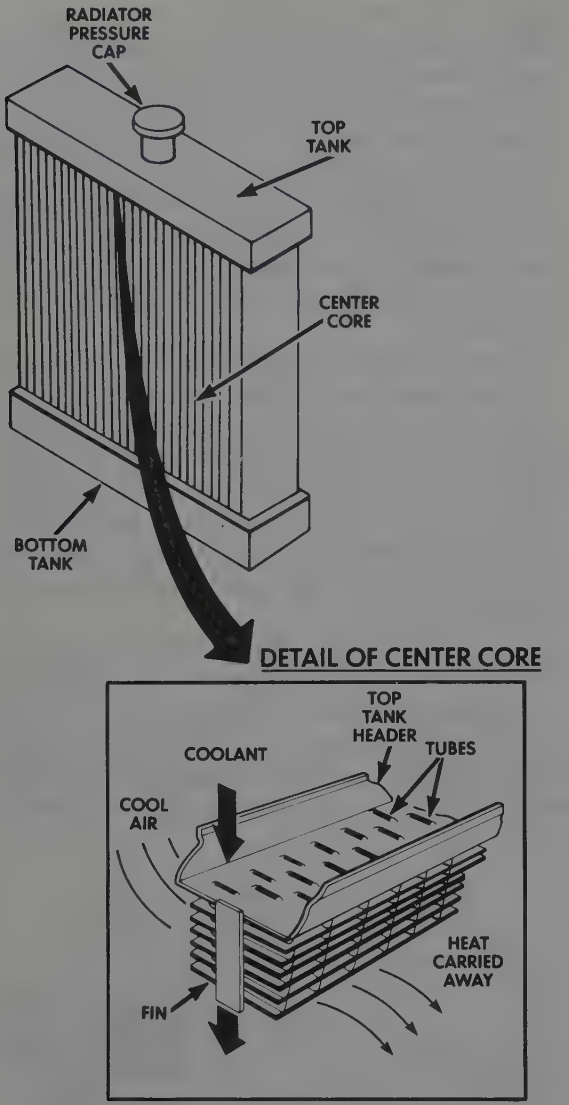

RADIATOR PRESSURE CAP
TOP TANK
CENTER CORE
BOTTOM TANK
DETAIL OF CENTER CORE
TOP TANK HEADER
COOLANT
TUBES
COOL AIR
HEAT CARRIED AWAY
FIN

Figure 6-24. The radiator removes heat from the coolant circulated around the engine parts.

out of the engine block and through a *radiator hose* into the radiator top tank. The hot coolant collects in the top tank and then flows down through narrow *tubes*. The tubes, as well as most of the other radiator parts, are made from aluminum or copper to provide good heat transfer. Heat passes out of the coolant and into the walls of the tubes. *Fins* are attached to each of the tubes. Heat moves from the tubes and into the fins. Air passages are designed around each fin. As air moves through the center core, it passes over the fins, which carry away the heat. Air and coolant flow through a radiator as shown in Figure 6-24. By the time the coolant reaches the bottom tank, its temperature has been lowered.

A radiator hose connected from the bottom tank to the coolant pump allows the coolant to re-enter the engine block. Radiator hoses are rubber, usually reinforced with steel wire. The radiator hoses have a difficult job to perform. Although the radiator is solidly mounted to the automobile chassis, the engine is attached on rubber mounts. Therefore, the engine rocks back and forth as it accelerates and decelerates. This rocking movement must not be transferred to the radiator, or it would soon break. Rubber hoses absorb this engine movement.

A **radiator pressure cap** is located on the top tank of the radiator (Figure 6-24). It can be removed to add coolant. The main purpose of the radiator pressure cap is to control system pressure and vacuum. The cooling system is sealed by the radiator pressure cap, which causes the system to operate at higher pressure than atmospheric pressure. The higher pressure raises the boiling point of the coolant, thus increasing the cooling efficiency of the radiator. A 15 PSI radiator pressure cap raises the boiling point of coolant to approximately 262°F at sea level.

A radiator pressure cap during *pressure relief* and *vacuum relief* is shown in Figure 6-25. The radiator pressure cap allows the coolant to expand through the *pressure valve* in the cap without building unnecessary pressure. The pressure valve closes as a result of expansion and coolant flow. A vacuum could cause the thin radiator tubes to collapse. If a vacuum forms, the *vacuum valve* opens to vent in air pressure.

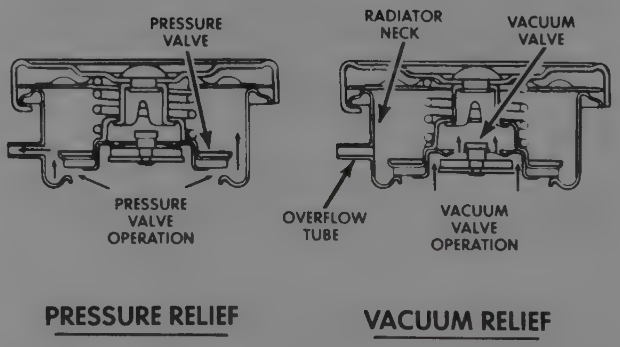

PRESSURE VALVE
RADIATOR NECK
VACUUM VALVE
PRESSURE VALVE OPERATION
OVERFLOW TUBE
VACUUM VALVE OPERATION
PRESSURE RELIEF
VACUUM RELIEF

Figure 6-25. A radiator pressure cap during pressure relief and vacuum relief. (Courtesy of American Motors Corporation)

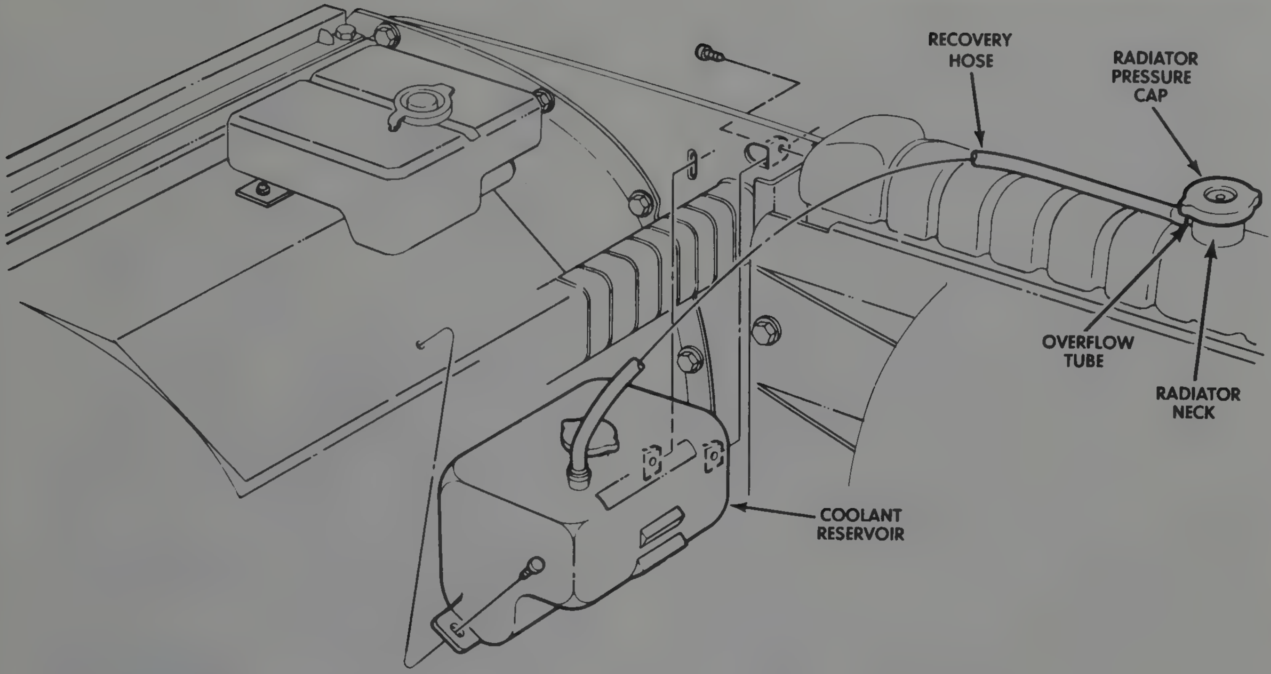

RECOVERY HOSE
RADIATOR PRESSURE CAP
OVERFLOW TUBE
RADIATOR NECK
COOLANT RESERVOIR

Figure 6-26. Coolant recovery system. (Courtesy of American Motors Corporation)

The *overflow tube* on the *radiator neck* is connected to a *coolant recovery system* as shown in Figure 6-26. As engine temperature increases, the coolant expands. The pressure valve (normally open) of the radiator pressure cap slowly transfers expanding coolant to the coolant reservoir while pressurizing the system. Any air trapped in the cooling system will be expelled during this period.

A **thermostat** is a mechanical device with parts that expand upon heating and contract upon cooling. It is needed in an automobile cooling system to regulate the temperature. Most thermostats work by opening or closing a valve to control the flow of coolant. This is a restriction valve actuated by a *thermostatic element*. The thermostat is mounted in a *housing* in the forward part of the intake manifold or cylinder head, under the *coolant outlet* (Figure 6-27). Thermostats are designed to open and close at predetermined temperatures to maintain efficient engine operating temperatures.

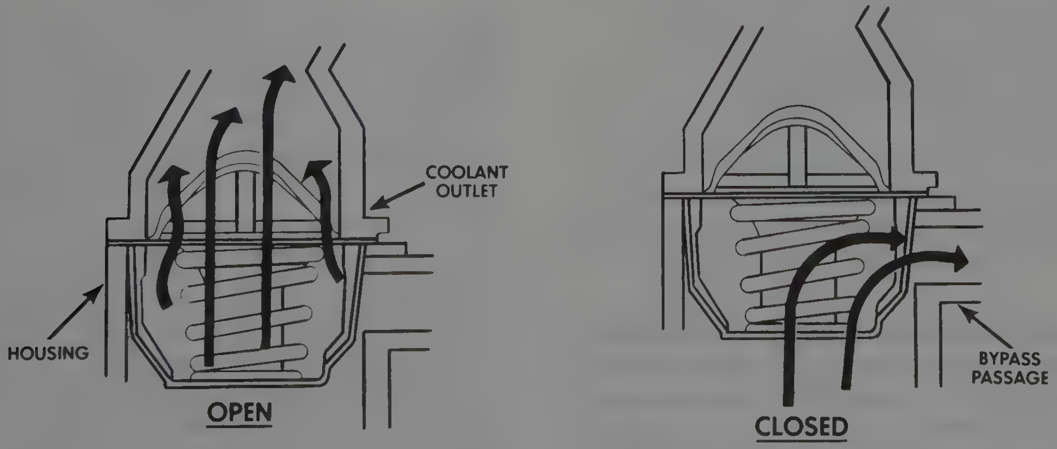

COOLANT OUTLET
HOUSING
OPEN
BYPASS PASSAGE
CLOSED

Figure 6-27. Coolant flow through an open and closed thermostat.

A *pellet-type* thermostat (Figure 6-28) uses a *wax pellet* (thermostatic element) to open and close the *valve*. As coolant flowing around the wax pellet heats up, the wax pellet expands. The wax pellet is attached to the valve through a *piston*. As it expands, the wax pellet pushes against a *rubber diaphragm* and opens the valve. Coolant can then flow through the thermostat and back to the radiator.

When the coolant is cold, the *coil spring* holds the valve closed and seated on the flange. Coolant cannot flow to the radiator. Instead it is routed through a bypass passage (Figure 6-27) in the block. This allows rapid warm-up time. As soon as the coolant heats up, the thermostat opens and allows coolant to flow to the radiator. Coolant flow with an open and closed thermostat is shown in Figure 6-27.

As mentioned earlier in this unit, air must be circulated through the center core of the radiator to dissipate the heat. Typically, the radiator is mounted in the front of the car behind the *grille*. Air passes through the grille and through the center core whenever the car is moving. If the car is moving, there is sufficient air flow for cooling. However, when the engine is running and the car is not moving, no air flows through the center core.

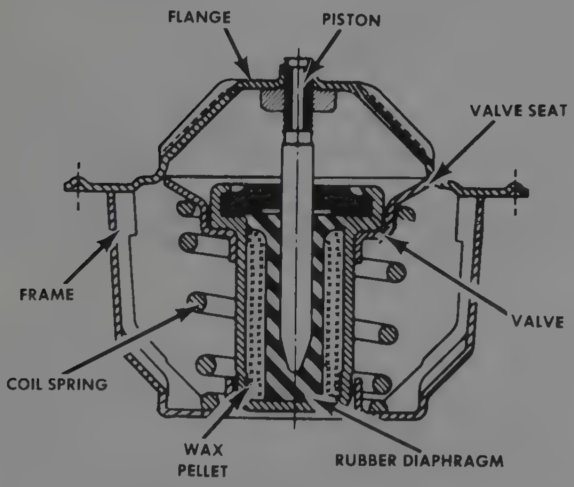


Figure 6-28. Cross section of a pellet-type thermostat. (Courtesy of Chevrolet Motor Division, General Motors Corporation)

To cool the center core, there is a **fan** between the radiator and the engine. The fan may be driven electrically (Figure 6-29) or mechanically (Figure 6-30). Often it is mounted to the same pulley that drives the coolant pump. As a drive belt, or fan belt, turns the pulley, the fan pulls air through the center core. Many engines use a mechanically driven fan with a hydraulic clutch. The hydraulic clutch varies the speed of the fan in relation to the engine temperature.

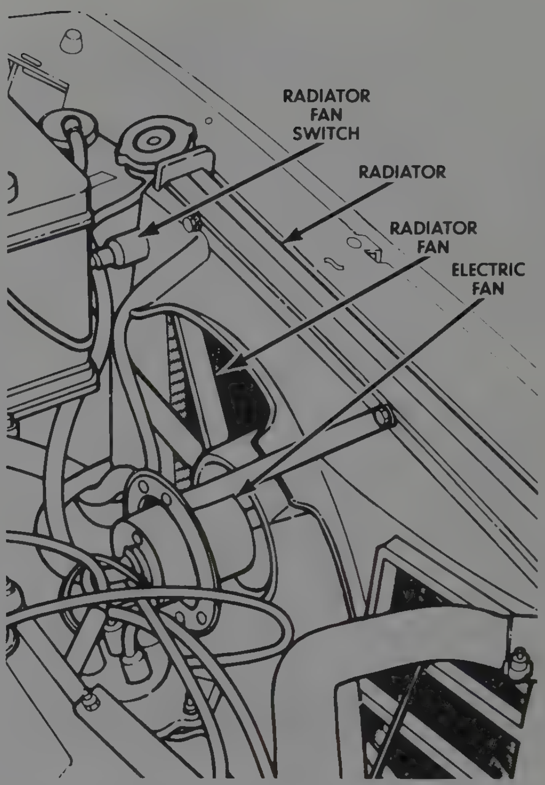


Figure 6-29. Cooling system with an electrically driven fan. (Courtesy of American Motors Corporation)

KEY TERMS

BDC: The abbreviation for bottom dead center.

Bypass valve: A valve assembly used to direct oil around a clogged oil filter.

Combustion chamber: Part of the cylinder head in which the burning of air and fuel takes place.

Compression ratio: A comparision of the volume for air and fuel when the piston is at BDC with the volume at TDC.

Compression stroke: One of the strokes of a four-stroke-cycle engine, in which the air and fuel is compressed.

Connecting rod: An engine part that connects the piston to the crankshaft.

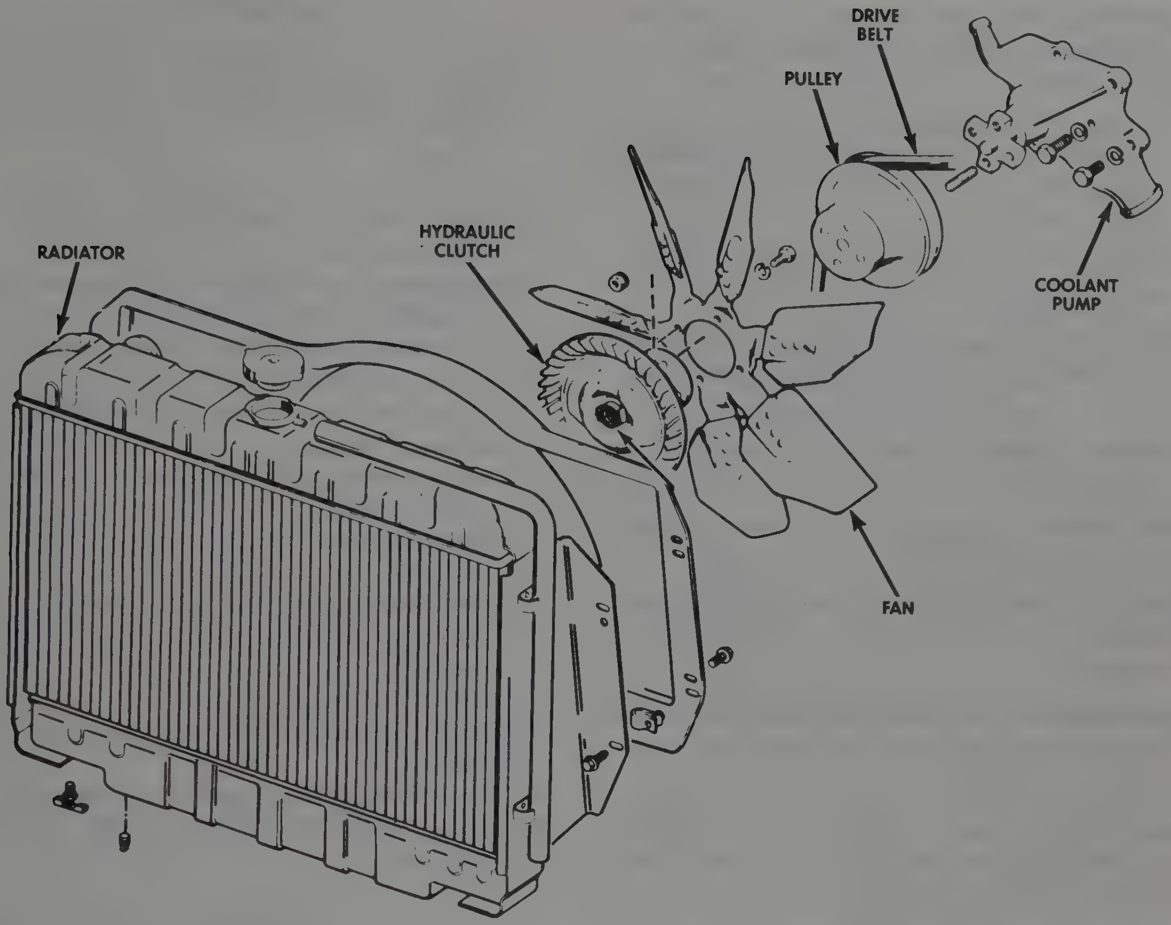


Figure 6-30. Cooling system with a mechanically driven fan with hydraulic clutch. (Courtesy of American Motors Corporation)

Coolant: Liquid used in a liquid cooling system to carry away heat — usually a mixture of ethylene glycol and water.

Coolant pump: Pump used to circulate coolant through the water jackets of the engine. It is also called a water pump.

Cooling system: An engine system used to regulate and control engine heat or temperature.

Crankshaft: An offset shaft to which the connecting rods are attached.

Cylinder: A tube closed at one end, in which an engine's piston moves up and down.

Cylinder number: A number assigned to each cylinder of an engine for identification.

Exhaust stroke: One of the strokes of a four-stroke-cycle engine, in which the exhaust gases are pushed out.

Fan: A device used to direct air through the radiator core to cool the liquid coolant.

Firing order: The sequence in which each cylinder receives a spark and delivers a power stroke.

Flywheel: A heavy wheel used to smooth out the power impulses on the crankshaft.

Four-stroke cycle: A series of events used to develop power in an automobile.

Intake Stroke: One of the strokes of a four-stroke-cycle engine, in which air and fuel enter the engine.

Internal combustion engine: An engine in which the burning of the fuel takes place inside the engine.

Lubrication: Forcing oil between moving engine parts to prevent metal-to-metal contact that causes friction and wear.

Lubrication system: An engine system designed to provide oil to engine parts for lubrication.

Oil filter: An assembly, usually one-piece construction, that uses a paper element to filter oil before it enters the critical engine components.

Oil galleries: Passages for oil flow in the cylinder block.

Oil pan: A metal pan mounted to the bottom of the engine and used to store lubricating oil.

Oil pump: A gear or rotor device used to circulate oil through the lubrication system.

Pickup screen: A screen that prevents large particles from entering the oil pump.

Piston: A round metal part attached to the connecting rod. It slides up and down in the cylinder.

Power overlap: The timing of power strokes of different cylinders to provide smooth operation of an engine.

Power stroke: One of the strokes of a four-stroke-cycle engine, in which power is delivered to the crankshaft.

Radiator: A large heat exchanger used to transfer the heat of the coolant to the outside air.

Radiator pressure cap: The cap on the top of the radiator used to regulate radiator pressure and vacuum.

Relief valve: A spring-loaded valve used to protect the lubrication system from excessive oil pressure.

TDC: The abbreviation for top dead center.

Thermostat: A mechanical device with parts that expand upon heating and contract upon cooling. It is used to control coolant flow in the cooling system.

Valve overlap: A short period of time when both valves (intake and exhaust) are open.

Valve train: An assembly of engine parts that open and close the passages for the intake of air and fuel and for the expulsion of exhaust gases.

Water jackets: Passages in the cylinder block and head for coolant flow.

SELF-CHECK

1. How does the crankshaft change up-and-down piston motion to circular motion?
2. What is the purpose of the engine's flywheel?
3. What is a piston stroke?
4. Describe the action in a cylinder on the intake stroke.
5. Describe the action in a cylinder on the compression stroke.
6. Describe the action in a cylinder on the power stroke.
7. Describe the action in a cylinder on the exhaust stroke.
8. How is the compression ratio of an engine determined?
9. What determines the firing order of an engine?
10. What is the purpose of the valve train?
11. What does the camshaft do in the valve train?
12. What is valve overlap?
13. What is the purpose of the lubrication system?
14. What is the purpose of the cooling system?
15. What is used for coolant in a liquid cooling system?

DISCUSSION TOPICS AND ACTIVITIES

1. Use an engine model or cut-away engine to observe the four-stroke-cycle principle. Identify each of the strokes.
2. Use a service manual and identify the cylinder number and firing order for an engine you are working on.

CERTIFICATION PRACTICE

1. A four-stroke-cycle engine is on an intake stroke. Mechanic A says the intake valve is open. Mechanic B says the piston is moving down. Who is correct?
   A. Mechanic A
   B. Mechanic B
   C. Both A and B
   D. Neither A nor B

2. A four-stroke-cycle engine is on a compression stroke. Mechanic A says both valves are closed. Mechanic B says the piston is moving down. Who is correct?
   A. Mechanic A
   B. Mechanic B
   C. Both A and B
   D. Neither A nor B
3. A four-stroke-cycle engine is on a power stroke. Mechanic A says both valves are closed. Mechanic B says the piston is moving down. Who is correct?
   A. Mechanic A
   B. Mechanic B
   C. Both A and B
   D. Neither A nor B
4. A four-stroke-cycle engine is on an exhaust stroke. Mechanic A says the exhaust valve is closed. Mechanic B says the piston is moving down. Who is correct?
   A. Mechanic A
   B. Mechanic B
   C. Both A and B
   D. Neither A nor B
5. The four-stroke-cycle occurs in:
   A. One crankshaft revolution
   B. Two crankshaft revolutions
   C. Four crankshaft revolutions
   D. Six crankshaft revolutions

ANSWERS

1: C, 2: A, 3: C, 4: D, 5: B

Unit 7 TROUBLESHOOTING ENGINE CONDITION

As stated in Unit 1, the first step in any tune-up is to determine that the engine is in satisfactory condition. An engine with worn internal components, such as piston rings or valves, cannot develop maximum power. Therefore, any additional work on the fuel, ignition, or emission systems will not improve power, mileage, or emission levels. This unit describes the various tests necessary to determine the condition of the engine.

DEVELOPING JOB COMPETENCIES

When you finish reading and studying this unit, you should be able to:

- Perform a compression test.
- Perform a cylinder leakage test.
- Perform a vacuum test.
- Measure cylinder power balance.
- Measure and adjust valve lash on mechanical lifters.

MEASURING ENGINE COMPRESSION

Compression is the "key" to engine power. The degree to which the air-fuel mixture is compressed (squeezed) on the compression stroke determines the total pressure developed on the power stroke to push the piston down. A *compression test* can be used to determine the condition of the piston rings and valve seat-to-face seal and to check for a defective *head gasket*..

A compression test is performed with a **compression tester** (Figure 7-1). The compression tester consists of a *pressure gage* and *fitting* (push-in type or screw-in type). The pressure gage has a scale divided into pounds per square inch (PSI). The pressure gage is attached to the engine cylinder by the push-in or screw-in type fitting. The push-in type fitting may have a tapered rubber tip and is held in the spark plug hole by hand. The screw-in type has a flexible hose that is useful for hard-to-reach spark plug holes, and it threads into the spark plug hole.

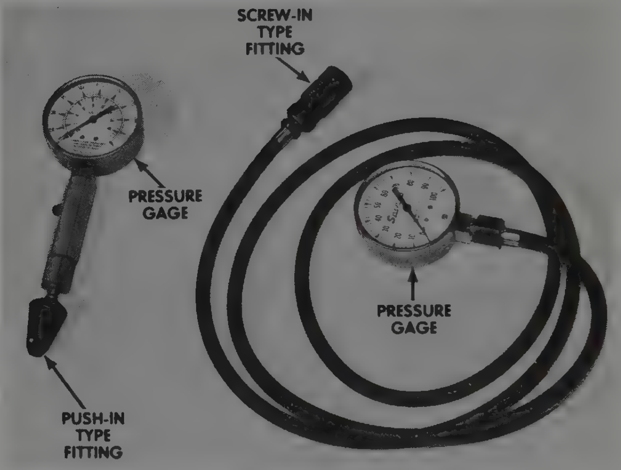


Figure 7-1. A compression tester is used to measure engine compression pressure.

To perform the compression test:

1. Run the engine until it reaches normal operating temperatures and then turn it off.
2. Remove the *spark plug wires*, also called *ignition wires*, from the *spark plugs* (Figure 7-2). **CAUTION: Use insulated pliers to pull off the wires by the boot. This will prevent damage to the spark plug wire and boot.**

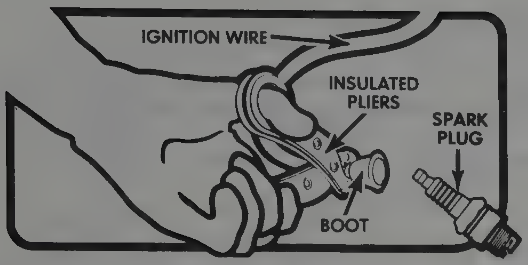


Figure 7-2. Proper way to remove the spark plug wires, also called ignition wires, using insulated pliers. (Courtesy of Sun Electric Corporation)

3. Remove any dirt from around the spark plugs.

4. Disconnect the ignition system by removing the *coil wire* (high-voltage lead) from the *distributor cap* and *grounding* it (Figure 7-3). Another way to disconnect the ignition system is to remove the *ignition switch connector* (not shown in Figure 7-3) from the distributor. *NOTE: On high energy ignition (HEI) systems, disconnect the battery wire from the ignition system at the distributor cap (Figure 7-4).*

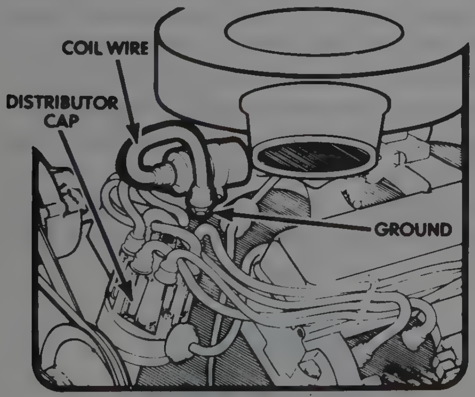


Figure 7-3. The ignition system is disconnected by removing the coil wire from the distributor cap and grounding the coil wire. (Courtesy of Sun Electric Corporation)

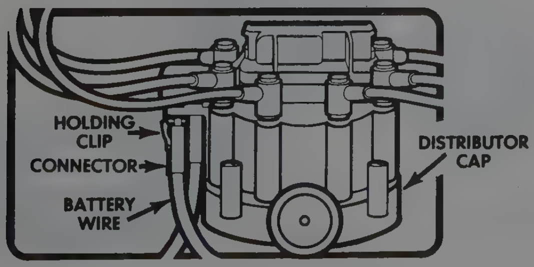


Figure 7-4. The HEI system is disconnected by removing the battery wire at the distributor cap. (Courtesy of Sun Electric Corporation)

5. The *throttle* and *choke plates* in the carburetor or *throttle plate* in the fuel injection system should be in the wide-open position during the compression test. (These plates are often referred to as valves.) This is accomplished by having someone hold the accelerator pedal to the floor or by blocking the *throttle linkage* in the wide-open position.

6. Connect the compression tester to the No. 1 cylinder (Figure 7-5).

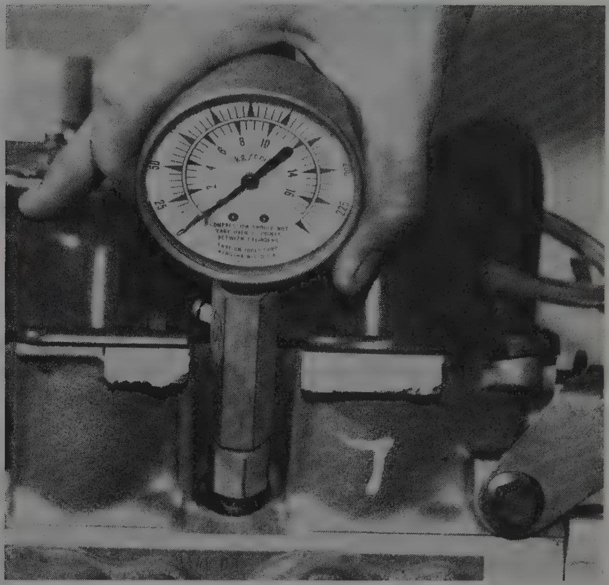


Figure 7-5. A compression tester is connected to an engine cylinder to measure compression.

7. Crank the engine until it has completed at least four compression strokes or goes to its maximum reading. Record the reading. Repeat the test for each cylinder. Check the manufacturer's specifications for the engine and compare them with your findings.

If a cylinder is below specifications and varies more than 20 PSI from the highest cylinder reading, a problem exists. The low-reading cylinder may have an improperly seated valve or worn or broken piston rings. The problem may be isolated by adding a small amount of engine oil to that cylinder through its spark plug hole. Crank the engine several times and take another compression reading. If the compression reading is now within specifications, the trouble is probably worn piston rings. (This is due to the oil sealing around the worn rings.) If the reading does not improve, the trouble is probably leaking valve seats.

COMPRESSION TESTING TROUBLESHOOTING

PROBLEM	POSSIBLE CAUSE	CORRECTIVE ACTION
READING 20 PSI BELOW SPECIFICATIONS IN ONE OR MORE CYLINDERS	WORN RINGS OR LEAKING VALVE SEATS	SERVICE ENGINE
READING ABOVE SPECIFICATIONS	EXCESSIVE CARBON BUILD-UP	REMOVE CYLINDER HEAD(S)
LOW READING IN TWO CYLINDERS NEXT TO EACH OTHER	FAULTY HEAD GASKET	REPLACE HEAD GASKET
READING REMAINS CONSTANT ON SOME STROKES, BUT CLIMBS HIGHER ON OTHER STROKES	STICKING VALVES	SERVICE ENGINE

Figure 7-6. Chart summarizing compression problems, possible causes of the problems, and corrective actions.

A higher than normal reading indicates a build-up of carbon deposits in the cylinder. If two adjacent cylinders have low compression readings, the head gasket is probably defective. If the reading remains the same on some strokes but climbs higher on other strokes, a valve may be sticking.

The chart in Figure 7-6 summarizes these compression problems, their possible causes, and corrective actions.

MEASURING CYLINDER LEAKAGE

The **cylinder leakage tester** shown in Figure 7-7 is another piece of equipment used to help determine engine condition. The cylinder leakage tester allows the mechanic to pinpoint exactly where compression is leaking and exactly how much is leaking.

Shop air is connected to the tester and goes through the tester and into a connection hose attached to a cylinder *spark plug hole* (Figure 7-8). The piston in the cylinder is positioned at TDC on the compression stroke. Air going into the cylinder is regulated with a knob on the tester. The mechanic fills the cylinder with air and observes the leakage scale. A perfect cylinder has no leakage (zero percent). A worn cylinder shows a high percentage of leakage.

To perform the cylinder leakage test:

1. Run the engine until is reaches normal operating temperature.
2. Clean the area around the spark plugs and remove the plugs.
3. Remove the *oil filler cap* and *radiator pressure cap*. **CAUTION: Coolant may be under pressure. Remove radiator pressure cap carefully.**
4. Connect the shop air hose to the tester. NOTE: *Follow the directions on the tester to calibrate the tester for the shop air pressure.*
5. Attach the connection hose to the spark plug hole for cylinder No. 1. NOTE: *Each cylinder to be tested must be on the compression stroke with the piston at TDC. Rotate the engine until piston No. 1 is on compression. Use the ignition timing marks on the crankshaft damper or front pulley as a guide. Remove the distributor*

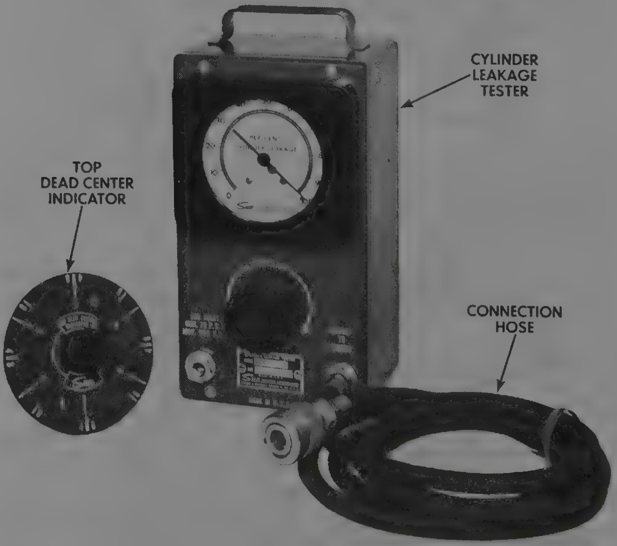


Figure 7-7. A cylinder leakage tester is used to pinpoint leakage from an engine's cylinders. (Courtesy of Sun Electric Corporation)

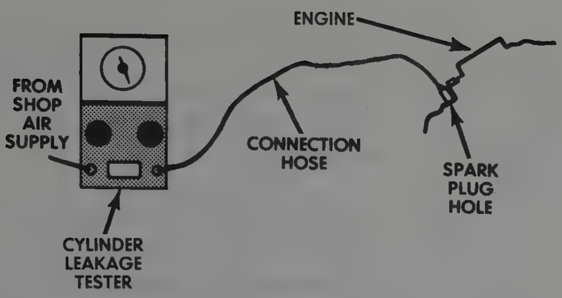


Figure 7-8. Shop air is directed through the tester and into the cylinder to find leakage.

cap and rotor. Install a TDC indicator (Figure 7-9) on the distributor shaft. The indicator shows how far to rotate the engine to position each cylinder on the compression stroke. Make a mark on the engine to use in aligning the indicator.

6. Use the control knob on the tester to fill the cylinder with air. NOTE: *Most engines will leak a small amount of air past the rings into the crankcase. However, any leak through an intake valve, an exhaust valve, head gasket, head, or excessive leakage past the piston rings indicates trouble.*

7. Listen and observe for the following:
   a. Air escaping through the carburetor or fuel injector air intake. This indicates a leaking intake valve.
   b. Air escaping through the exhaust pipe. This indicates a leaking exhaust valve.
   c. Air escaping from the oil filler cap. This indicates leakage past the piston rings and into the crankcase.

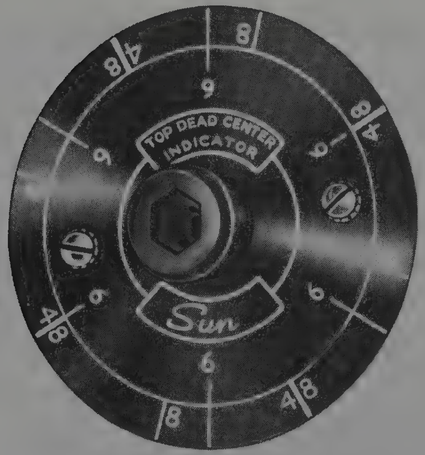


Figure 7-9. The TDC indicator is mounted on the distributor to position each cylinder on the compression stroke. (Courtesy of Sun Electric Corporation)

   d. Bubbles in the radiator. This indicates a head gasket leak allowing air to enter the cooling system.

8. Turn the air off and disconnect the connection hose from the engine. Rotate the engine until the next cylinder is on TDC.

9. Attach the connection hose from the cylinder previously tested, and install it in the next cylinder in the engine's firing order.

Repeat the test for each cylinder. The readings should be about even and should show less than 20% leakage. Readings of 20% or more indicate excessive leakage and loss in compression. A high percent of leakage on adjacent cylinders indicates a leaking head gasket or a crack in the cylinder head. The chart in Figure 7-10 summarizes cylinder leakage problems, their possible causes, and corrective actions.

CYLINDER LEAKAGE TROUBLESHOOTING CHART

PROBLEM	POSSIBLE CAUSE	CORRECTIVE ACTION
AIR ESCAPING THROUGH CARBURETOR OR FUEL INJECTOR AIR INTAKE	LEAKING INTAKE VALVE	RECONDITION VALVES
AIR ESCAPING THROUGH EXHAUST PIPE	LEAKING EXHAUST VALVE	RECONDITION VALVES
AIR ESCAPING THROUGH OIL FILLER CAP	LEAKING PAST PISTON RINGS	RECONDITION ENGINE
BUBBLES IN THE RADIATOR	HEAD GASKET LEAKING	INSTALL NEW GASKET
LEAKAGE FROM TWO ADJACENT CYLINDERS	HEAD GASKET LEAKING OR CRACKED CYLINDER HEAD	INSTALL NEW HEAD GASKET OR REPAIR OR REPLACE CYLINDER HEAD

Figure 7-10. Chart summarizing cylinder leakage problems, possible causes of the problems, and corrective actions.

MEASURING ENGINE VACUUM

Another useful tool to help determine engine condition is a **vacuum gage** (Figure 7-11). It is connected to the *intake manifold* and measures the vacuum while the engine is running. Vacuum is measured in inches of mercury (In. Hg). The scale range is from zero to about 30". An engine in good condition with good rings and valves in each cylinder will develop a high vacuum as each cylinder develops an intake stroke. An engine in poor condition with leaky rings or valves will not develop as strong a vacuum. To measure engine vacuum:

1. Run the engine until it reaches normal operating temperature.
2. Locate a vacuum hose that is attached directly to the intake manifold.
3. Pull the vacuum hose off and plug it. Attach the *connection hose* from the *vacuum gage* to the *intake manifold* (Figure 7-12). NOTE: *Make sure all engine vacuum hoses are connected or plugged so that vacuum will not be lost.*
4. Start the engine and let it idle. Observe the action of the vacuum gage needle. Check the reading against specifications. NOTE: *Low readings on many late-model cars are normal because of retarded engine timing.*

The chart in Figure 7-13 summarizes vacuum problems, their possible causes, and corrective actions.

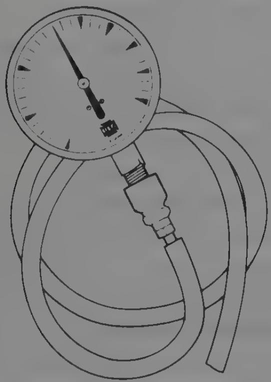


Figure 7-11. A vacuum gage can be used to help determine engine condition. (Courtesy of Ford Motor Company)

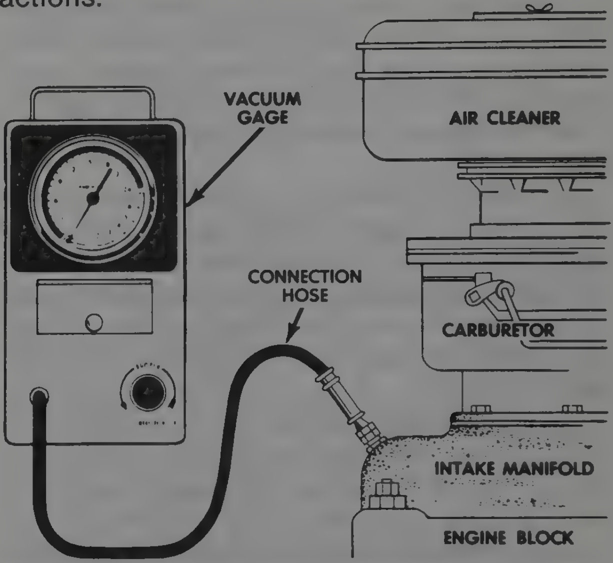


Figure 7-12. A vacuum gage is connected to the intake manifold. (Courtesy of Sun Electric Corporation)

VACUUM GAGE TEST TROUBLESHOOTING CHART

PROBLEM	POSSIBLE CAUSE	CORRECTIVE ACTION
STEADY READING LOWER THAN NORMAL	RETARDED TIMING OR WORN RINGS	SERVICE AS REQUIRED
NEEDLE "FLOATS" OVER WIDE RANGE	LEAKING HEAD GASKET	REPLACE HEAD GASKET
REGULAR DROP OF SEVERAL INCHES FROM NORMAL	LEAKING VALVES	SERVICE VALVES
RAPID NEEDLE FLUCTUATIONS WHEN ENGINE IS ACCELERATED	WEAK VALVE (COIL) SPRINGS	RECONDITION VALVE TRAIN
NEEDLE VIBRATES AT IDLE BUT STEADY DURING ACCELERATION	WORN VALVE GUIDES	RECONDITION CYLINDER HEADS

Figure 7-13. Chart summarizing vacuum problems, possible causes of the problems, and corrective actions.

MEASURING CYLINDER POWER BALANCE

In a **power balance test**, each cylinder's ignition is grounded or disconnected to determine whether any power output variation exists. Years ago, mechanics had a crude way of performing a cylinder power balance test. They would ground or pull off the spark plug wires one at a time while the engine was idling, listening for any change in the speed of the engine. When a spark plug wire on a cylinder in bad condition is disconnected, engine speed is not noticeably affected. This principle is the basis of today's testing equipment for cylinder power balance.

Almost all tune-up equipment, from small portable testers to computerized testers, have the function called *cylinder power balance*, also called *power check* or *cylinder output*. The function allows the technician to electronically ground or disconnect each spark plug wire and note (read) either engine speed or engine vacuum change. The test results indicate whether or not any cylinder, or combination of cylinders, is developing its share of drive power during the power stroke. The less power produced by a given cylinder, the less RPM will be lost, and the less the manifold vacuum will drop when that cylinder is grounded or disconnected. This test provides a quick check of engine condition. If the engine passes this test, the more time-consuming tests for compression, vacuum, and cylinder leakage are not necessary.

Most testers with the cylinder power balance function have a set of *cylinder selector buttons* (Figure 7-14). When depressed, they ground or disconnect the ignition for that cylinder. The manufacturer's instructions supplied with the testing equipment should be followed when performing this test.

CAUTION: Some manufacturers recommend that equipment for recirculating exhaust gases be disconnected when the cylinder power balance is performed. When a cylinder is grounded or disconnected, unburned hydrocarbons (HC) can enter the catalytic converter and cause it to overheat. For this reason, some car manufacturers do not recommend performing the test or recommend very short test intervals.

The engine speed for the test is specified in the instructions supplied with the tester. Testing speeds vary from idle up to 3,000 RPM. As each button is depressed, the tester's scale should be observed. A typical scale is shown in Figure 7-15. The results (engine RPM) from each cylinder are then recorded.

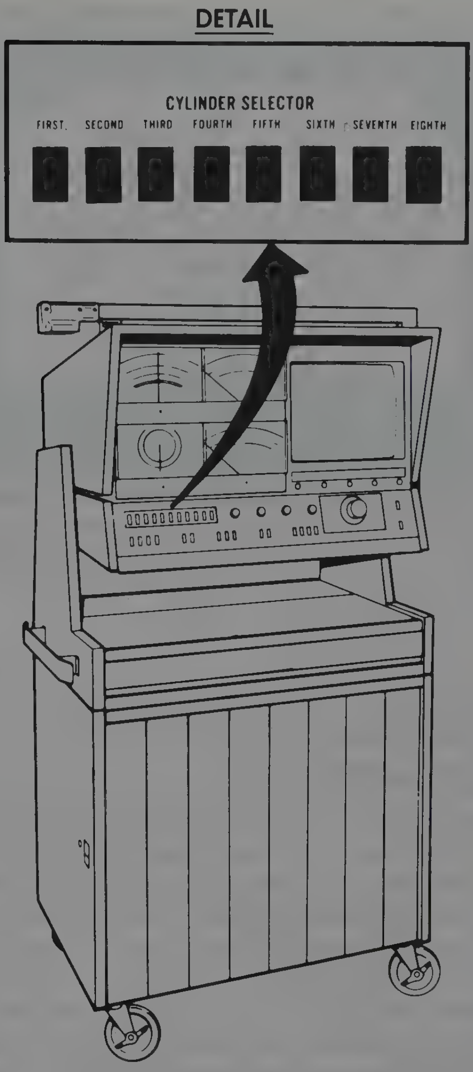


Figure 7-14. Cylinder selector buttons are used to short out ignition for the power balance test. (Courtesy of Marquette Products, Automotive Division of Applied Power, Inc.)

Engine condition is determined with this test by noting the amount of variation between cylinders. If the observed reduction in RPM is about the same for all cylinders (within specified limits), each cylinder is developing an equal amount of power. If the reduction in RPM is not about the same for all cylinders, the cylinder or cylinders with less reduction have ignition, carburetion, or engine problems. The tune-up cannot be completed until the cause of the irregular power readings is determined by a compression, vacuum, or cylinder leakage test.

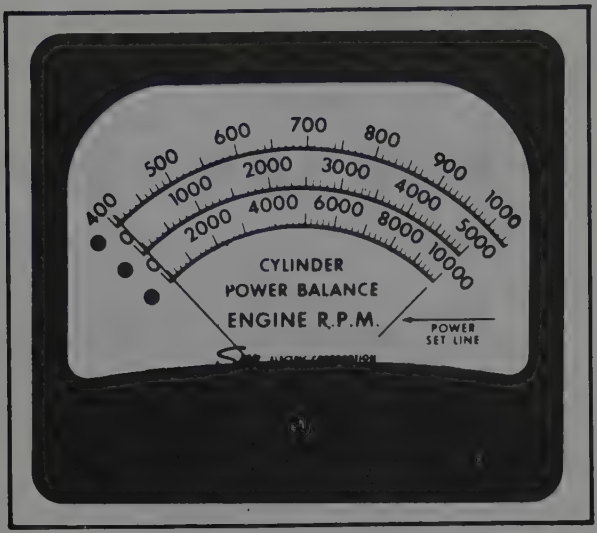


Figure 7-15. Typical scale on a tester used to determine cylinder power balance. (Courtesy of Sun Electric Corporation)

MEASURING AND ADJUSTING VALVE LASH

Valve lash, or *valve clearance*, is a space provided in a valve train equipped with *solid lifters* to allow for expansion. Valve lash must be periodically inspected and maintained at the correct clearance. Engines with *hydraulic valve lifters* do not require adjustment. However, engines with solid lifters may specify this adjustment as part of the vehicle's tune-up, because incorrect valve lash can affect engine performance.

If the valve lash is too wide, the engine will be noisy. More important, the wide space in the valve train can result in worn camshaft and lifter contact faces. Push rods may also be bent. Eventually, if the clearance becomes large enough, the valve timing will be changed enough to result in poor engine performance.

Valve lash that is too narrow results in even more serious problems than valve lash that is too wide. If the valve train does not have clearance to allow for expansion, a valve may be prevented from closing tightly on its seat. This prevents the valve from sealing the combustion chamber and results in poor engine performance. When a valve is held off its seat, it becomes very hot, because it is not able to move heat away from the *valve head* into the valve seat in the *cylinder head.* The high temperatures can quickly melt the valve head.

Before valve lash is measured and adjusted, the correct service literature should be consulted. The shop or repair manual for the vehicle will present a step-by-step procedure for the valve adjustment as well as specifications for clearance. Some valve trains must be adjusted only when the engine is cold, while some must be adjusted only when the engine is hot. Since engine temperature changes the clearance, the mechanic must be careful to follow the correct procedure.

Some engines have different clearance specifications for the intake and exhaust valves. This is due to the higher exhaust valve temperatures. It is also due to the fact that different metals with different expansion rates are often used in the two valves. If this is the case, the exhaust valve clearance will normally be larger.

In an engine with *adjustable rocker arms and solid lifters*, the valve lash should be measured by using a feeler gage set as shown in Figure 7-16. The clearance must be measured when the lifter is resting on the heel, or low point, of the cam. The service or shop manual will specify how to position the engine so that the valves are in the correct position for adjustment. A *feeler gage* is selected that is the same as the clearance specification. If the feeler gage blades will not slide into the space, the *adjustment screw* must be turned to increase the valve clearance. If the feeler blade fits into the space too loosely, the adjustment screw must be turned to reduce the clearance. The feeler gage should fit with a slight drag.

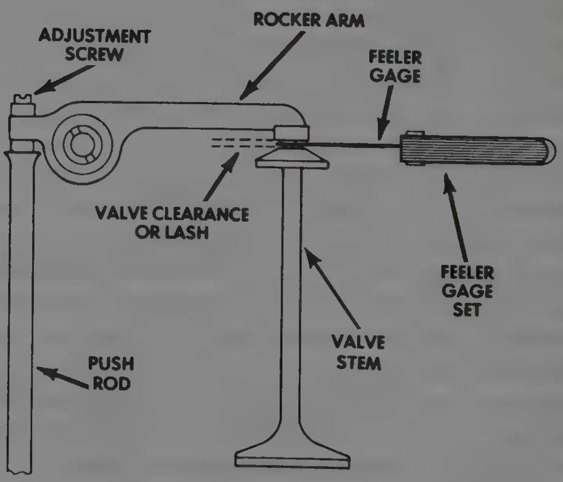


Figure 7-16. Valve clearance is measured by sliding the correct feeler gage between the rocker arm and valve stem.

Ball-and-stud rocker arm assemblies are adjusted by turning the nut on top of the stud as shown in Figure 7-17. (The feeler gage is used the same way here as shown in Figure 7-16.)

On some overhead camshaft engines, the valve lash is adjusted with an adjustable tappet, cam follower, or rocker arm. The valve clearance is measured by inserting a feeler gage between the camshaft and follower. The cam must be positioned so that the heel of the cam is contacting the follower. Adjustments are made by adjusting the length of the rocker arm or tappet.

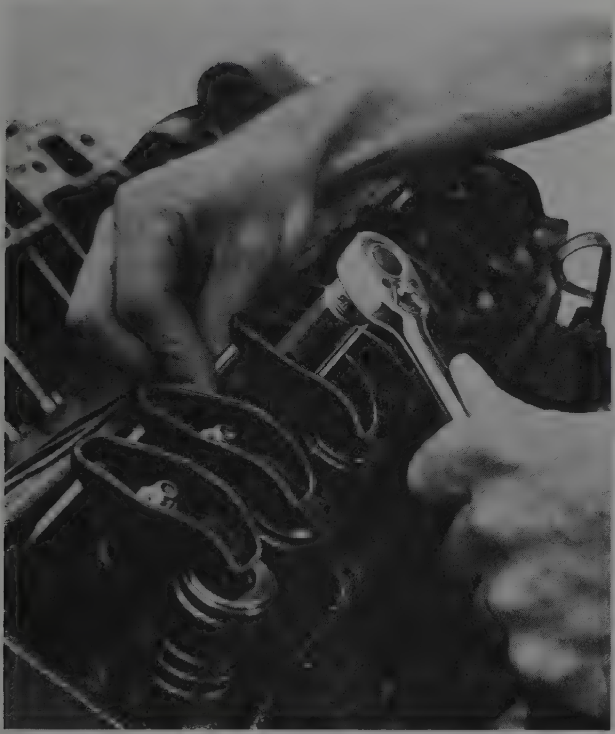


Figure 7-17. Adjusting ball-and-stud rocker arm assemblies. (Courtesy of Chevrolet Motor Division, General Motors Corporation)

Many overhead camshaft engines use *valve adjusting discs* as shown in Figure 7-18. These discs fit between the *follower,* or *lifter*, and the *cam lobe* on the camshaft. Thicker or thinner discs are installed to change the valve lash. The discs are changed by pushing down on the follower and compressing the *valve springs*. A *compressing disc tool* is used for this purpose. A small *magnet* is used to pull out the disc as shown in Figure 7-19.

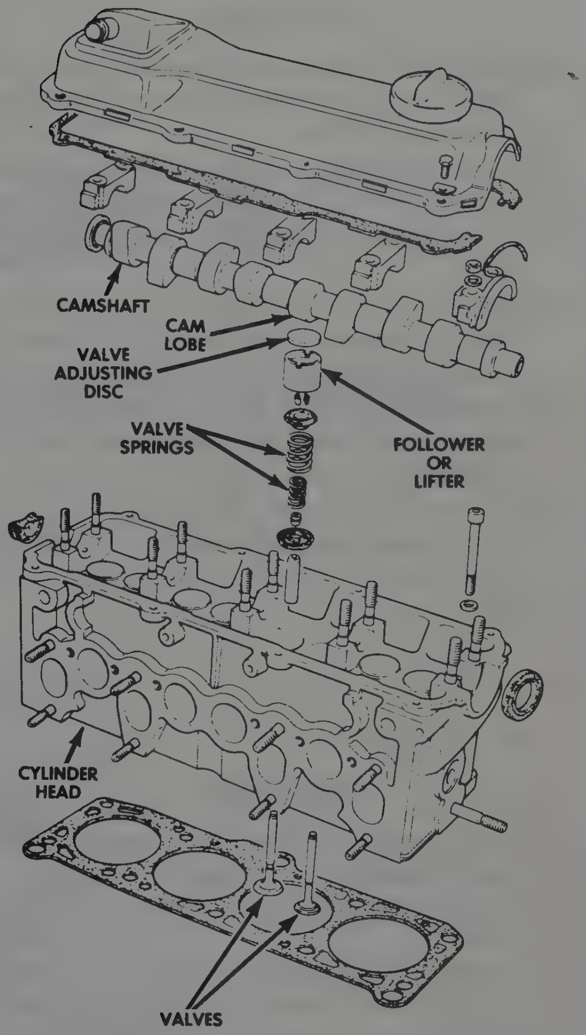


Figure 7-18. Many overhead cam valve adjustments are made with valve adjusting discs. (Courtesy of Chrysler Corporation)

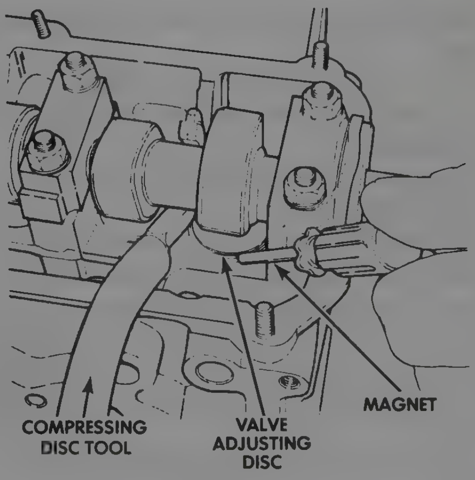


Figure 7-19. Changing a valve adjusting disc to adjust valve lash. (Courtesy of Chrysler Corporation)

KEY TERMS

Compression tester: A pressure gage and fitting used to measure compression pressure in a cylinder.

Cylinder leakage tester: A tester that allows the mechanic to pinpoint exactly where compression is leaking and exactly how much.

Power balance test: A test in which each cylinder's ignition is grounded or disconnected to determine the power output variation.

Vacuum gage: A tester that is connected to the intake manifold and measures the vacuum while the engine is running.

Valve lash: The space or clearance in a mechanical valve train that provides for expansion. Also referred to as valve clearance.

SELF-CHECK

1. What problems can be located using a compression tester gage?
2. List the steps involved in a compression test.
3. How can a ring or valve problem be determined using oil and a compression tester gage?
4. What can cause a higher than normal compression reading?
5. What is the purpose of a cylinder leakage tester?
6. List the steps involved in a cylinder leakage test.
7. When air escapes from the exhaust pipe during a cylinder leakage test, what is the problem?
8. How is engine condition determined with a vacuum gage?
9. List the steps involved in a vacuum test.
10. If a vacuum gage needle floats over a wide range, what could be the cause?
11. What is a power balance test?
12. How is a power balance test performed?
13. How can valve lash affect engine performance?
14. Explain how to measure valve lash.
15. How are valve adjusting discs used to adjust valve lash?

DISCUSSION TOPICS AND ACTIVITIES

1. Using an engine with a "weak" cylinder, do a compression, leakage, vacuum, and power balance test. Did each test indicate a problem? Why or why not?
2. What is the quickest engine condition test? Why?

CERTIFICATION PRACTICE

1. Oil is added to a cylinder with low compression, and the compression pressure on retesting raises compression to specifications. The problem is:
   A. Worn valve seats
   B. Worn piston rings
   C. Blown head gasket
   D. Worn valve guides
2. Before actually measuring engine compression with the compression tester:
   A. Warm up the engine
   B. Ground the ignition
   C. Open the throttle
   D. All of the above
3. Air is directed into the cylinder from a tester during a:
   A. Compression test
   B. Vacuum test
   C. Cylinder leakage test
   D. None of the above
4. Each engine cylinder's ignition is grounded or disconnected during a:
   A. Power balance test
   B. Vacuum test
   C. Leakage test
   D. All of the above
5. Valve lash is measured:
   A. With a feeler gage
   B. When the valve is on the heel of the cam
   C. Both A and B
   D. Neither A nor B

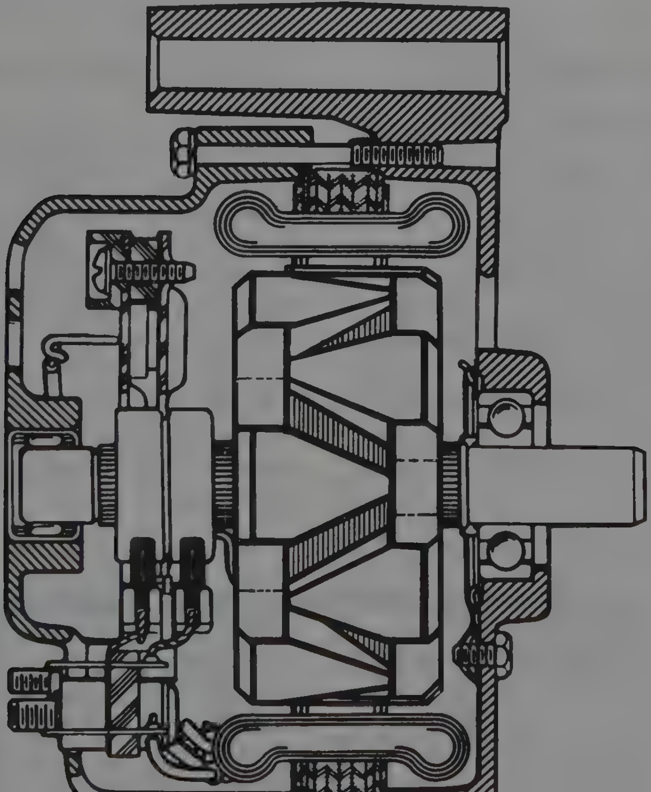
ANSWERS

1: B, 2: D, 3: C, 4: A, 5: C

SECTION III

Starting and Charging Systems

Unit 8. Starting System Operation
Unit 9. Charging System Operation
Unit 10. Starting and Charging System Prechecks



Courtesy of Ford Motor Company

Unit 8 STARTING SYSTEM OPERATION

The function of the starting system is to crank the engine fast enough to allow the engine to start. The starting system and ignition system must work together for good engine starting. The tune-up technician must understand the operation of the starting system because malfunction of a starting system component could prevent the engine from starting. This unit explains how each of the components of the starting system operates.

DEVELOPING JOB COMPETENCIES

When you finish reading and studying this unit, you should be able to:

- Describe the basic parts of a starting system.
- Describe the parts of a battery.
- Explain the chemistry of a battery during charging and discharging.
- Describe the parts and explain the basic principles of operation for a starter motor.
- Explain the purpose and operation of a starter motor drive.
- Explain the purpose and operation of a solenoid.

STARTING SYSTEM COMPONENTS

The starting system is comprised of the *battery*, the *key switch*, the *starter motor* with its drive mechanism, and the *solenoid*. These components are connected together and work as a team to crank the engine. The pictorial wiring diagram in Figure 8-1 illustrates a typical starting system circuit.

When the driver turns the key switch to START, current flows from the battery through the key switch to the solenoid. The solenoid allows battery current to flow directly from the battery to the starter motor, which in turn cranks the engine.

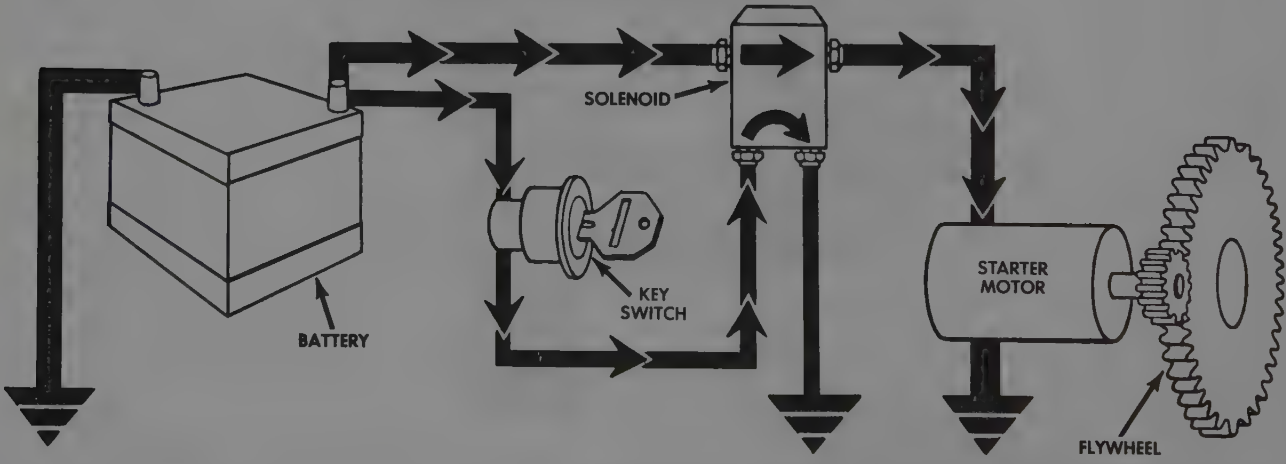


Figure 8-1. Simplified pictorial wiring diagram for a starting system circuit. (Courtesy of Chevrolet Motor Division, General Motors Corporation)

Battery

The automotive storage battery serves as an energy "bank." It receives energy from the vehicle's *charging system* (covered in Unit 9) and stores it until needed; then it provides this energy to the various vehicle electrical systems on demand. The battery converts electrical energy into chemical energy (during charging), then back into electricity (during discharging), by means of a fully reversible chemical reaction.

Principles of Battery Operation. A simple battery cell is composed of two *plates* made of different metals that are placed in a container of acid solution called **electrolyte** (Figure 8-2). The acid in the electrolyte reacts with the **positive (+) plate** to release electrons [negative (−) charges]. They transfer to the other plate, giving it a negative (−) charge. When the battery is fully charged, the **negative (−) plate** has an excess of electrons. If this battery is connected into a simple circuit, as shown in Figure 8-3, the excess electrons are pulled away from the negative (−) plate and flow to the light bulb. Chemical action is still going on inside the cell; but as this action continues, the electrolyte becomes weaker and weaker, and the negative (−) and positive (+) plates become more and more alike in chemical composition. Eventually, all the electrons are used up, the light bulb goes out, and the battery is discharged.

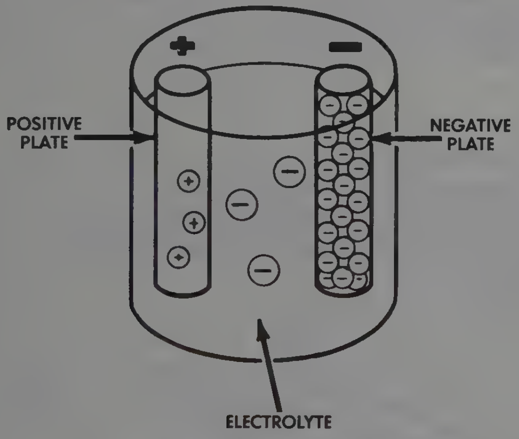


Figure 8-2. Simple battery cell.

In an automotive storage battery, the **active material** of **sponge lead** (Pb), and **lead peroxide** (PbO_2) make up the negative (−) and positive (+) plates, respectively. The electrolyte is a mixture of sulfuric acid (H_2SO_4) and water (H_2O). When a cell is discharging by completing an external electrical circuit (as occurs when the engine is cranked), the sulfuric acid acts on both positive (+) and negative (−) plates to form a chemical compound called *lead sulfate* ($PbSO_4$). The electrolyte becomes weaker in direct proportion to the amount of electricity used. When a certain amount of the sulfuric acid has combined with the plates, the battery can no longer deliver current at a useful voltage and the battery is discharged.

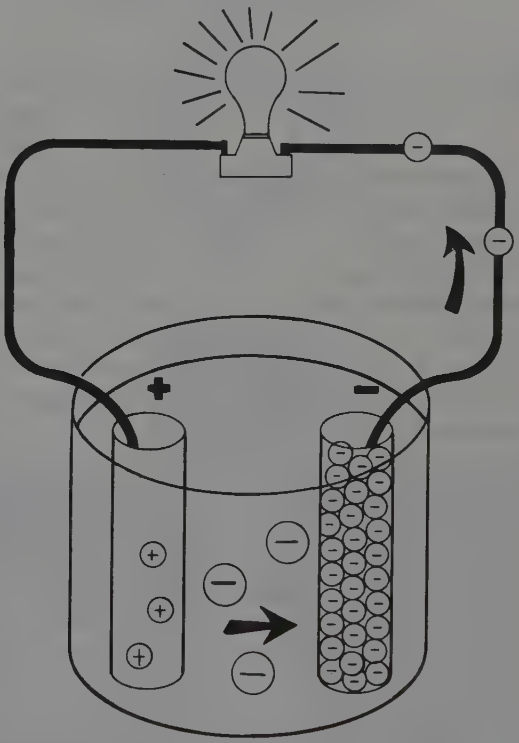


Figure 8-3. The battery cell provides electron flow current to light the light bulb.

Battery Construction. An automotive storage battery, sometimes referred to as a *lead-acid storage battery*, incorporates *positive* (+) and *negative* (−) *plate groups* as shown in Figure 8-4. Each plate group is made by lead burning (welding) a number of plates to a lead casting called a *plate strap*. The plate strap includes a *battery post.* The two groups are assembled with alternate negative (−) and positive (+) plates. Negative (−) plate groups normally contain one more plate than the positive (+) plate groups. This means that negative (−) plates are on the outside of the assembly.

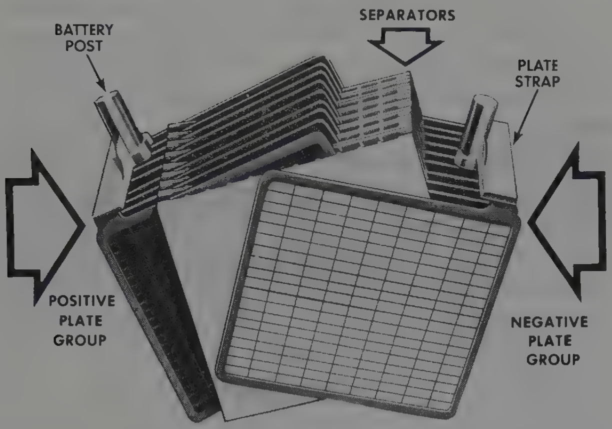


Figure 8-4. Plate groups and separators. (Courtesy of Chevrolet Motor Division, General Motors Corporation)

A **separator** is placed between any two plates in the group. The separators in most batteries are thin sheets of insulation of microporous rubber, fiberglass, or purified wood. All separators have one ribbed side facing the positive (+) plate. The ribs are vertical to improve circulation of the electrolyte to the positive (+) plates and to channel any loosened particles downward.

The assembly of a positive (+) and a negative (−) plate with a separator forms an *element* (Figure 8-5). There may be elements of any number or size, depending upon how much energy is to be stored. The greater the plate surface area per element, the higher the output during high rates of discharge, especially at low temperatures.

When the element is placed into a container with an acid solution, it becomes a **cell** (Figure 8-6), the basic component of the battery. No matter what the size of the cell or the number of plates in the element, the open circuit voltage of a fully charged cell is only a little over 2 volts.

When the negative *terminal* of one cell (Figure 8-5) is connected to the positive terminal of another cell, a series connection exists. With a series connection, the voltage is the sum of all the cells connected together. The battery voltage is the sum of the voltage of its cells. Six cells connected together provides 12 volts (Figure 8-6).

Automotive battery containers are one molded piece, usually made of hard rubber or plastic. They must withstand extremes of heat and cold, as well as mechanical shock, and must resist acid. The bottom of each cell compartment has four narrow, molded *rests*, or *bridges*, on which the element sits. This minimizes the danger of short circuits resulting from sediment that falls from the plates onto the bridges where the plates sit.

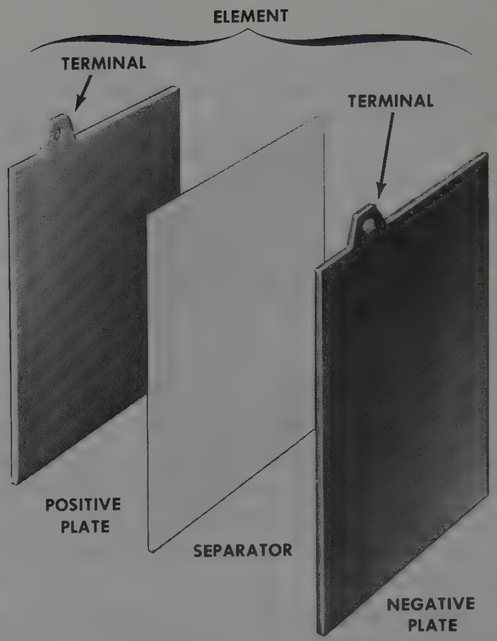


Figure 8-5. A separator fits between the positive (+) and negative (−) plates to form an element. (Courtesy of Chevrolet Motor Division, General Motors Corporation)

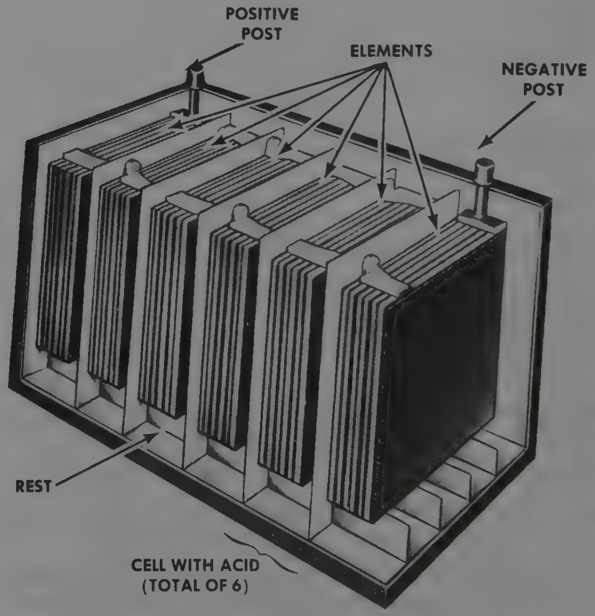


Figure 8-6. Six cells are connected together in series to provide 12 volts. (Courtesy of Chevrolet Motor Division, General Motors Corporation)

To connect battery cells in series, the *elements* are arranged with the *negative* (−) *terminal* of one cell next to the *positive* (+) *terminal* of the next cell (Figure 8-7). *Cell connectors* are then placed through the *partition* and welded together to connect the cells in series. There are five cell connectors in a 12-volt battery.

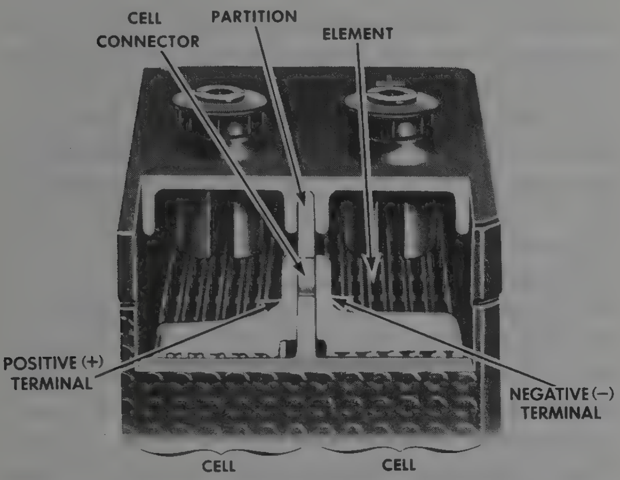


Figure 8-7. Partial view of two cells, showing the cell connector. (Courtesy of Delco Remy, Division of General Motors Corporation)

A one-piece molded cover on the battery forms an acid-tight seal. Some batteries use a *vent cap* over each *cell* as shown in Figure 8-8. The vent cap fits in threaded or tapered holes and can be removed for inspection and for adding electrolyte when necessary. A hole in the vent cap allows hydrogen gas to escape as the battery is charged.

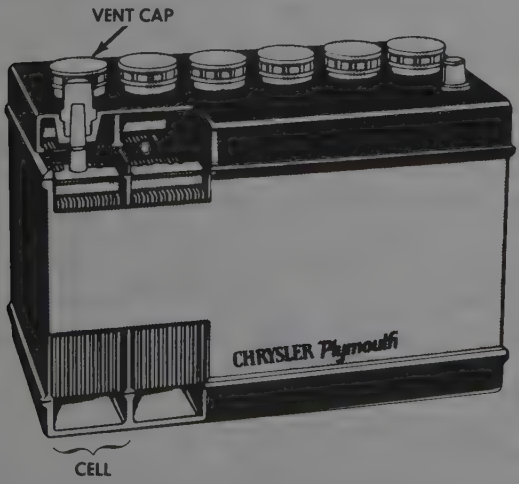


Figure 8-8. Battery with vent caps. (Courtesy of Chrysler Corporation)

Some batteries are equipped with a specially designed *vent plug* with a *transparent rod* extending through its center (Figure 8-9). When the electrolyte is at the proper level, the lower tip of the rod is covered, and the exposed top of the rod appears very dark. When the electrolyte level falls below the tip of the rod (as shown in Figure 8-9), the top of the rod will glow. This type of vent plug allows the technician to tell at a glance if water is needed without removing the vent plugs. It is used in only one cell, because when the electrolyte level is low in one cell, it is normally low in all cells.

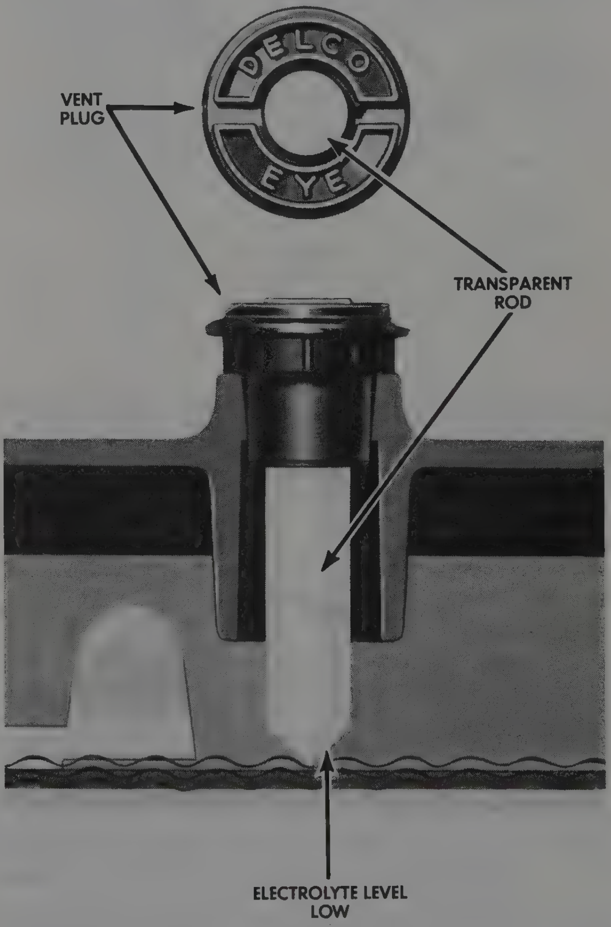


Figure 8-9. The vent plug shows when the electrolyte level is low. (Courtesy of Delco Remy, Division of General Motors Corporation)

Many batteries are **maintenance-free** (Figure 8-10) and do not have cell caps or vents. Instead, the battery is sealed or has a removable top strip. Since there are no cell vents, the hydrogen and oxygen are routed into an expansion area within the battery where the gas condenses into water. The water then runs back into the cells. This design does not require frequent inspection and water filling.

Since batteries without vent caps cannot be tested with a hydrometer, many are equipped with a *built-in hydrometer* or *charge indicator*. The hydrometer is used to tell if the battery is charged or discharged. (See Units 4 and 10 for additional information on the hydrometer.)

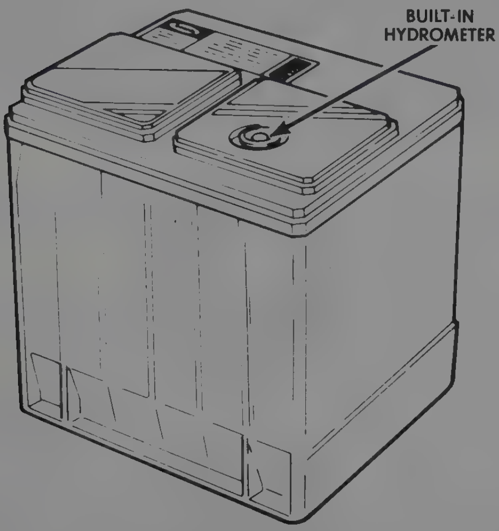


Figure 8-10. Maintenance-free batteries do not have cell vent caps but sometimes incorporate a built-in hydrometer. (Courtesy of Chevrolet Motor Division, General Motors Corporation)

Battery Chemistry. As mentioned earlier under the heading of "Principles of Battery Operation," the four basic ingredients of the automotive (lead-acid) storage battery are:

1. Lead peroxide (PbO_2)
2. Sponge lead (Pb)
3. Sulfuric acid (H_2SO_4)
4. Water (H_2O)

A current flow is caused whenever there is a chemical reaction between the two dissimilar metals of the plates and the sulfuric acid in the electrolyte. Electrolyte is made up of a mixture of approximately 36% sulfuric acid and 64% water by volume. The chemistry of a battery during *charging* and *discharging* is shown in Figure 8-11.

When the battery is connected to an external circuit, current begins to flow from the battery. This is known as the *discharge cycle*. The lead peroxide (PbO_2) in the positive (+) plate is a compound of lead (Pb) and oxygen (O_2). Sulfuric acid is a compound of hydrogen (H_2) and sulfate (SO_4). Oxygen in the active material of the positive (+) plate combines with hydrogen from the sulfuric acid to form water (H_2O). At the same time, lead in the active material of the positive (+) plate combines with the sulfate, forming lead sulfate ($PbSO_4$).

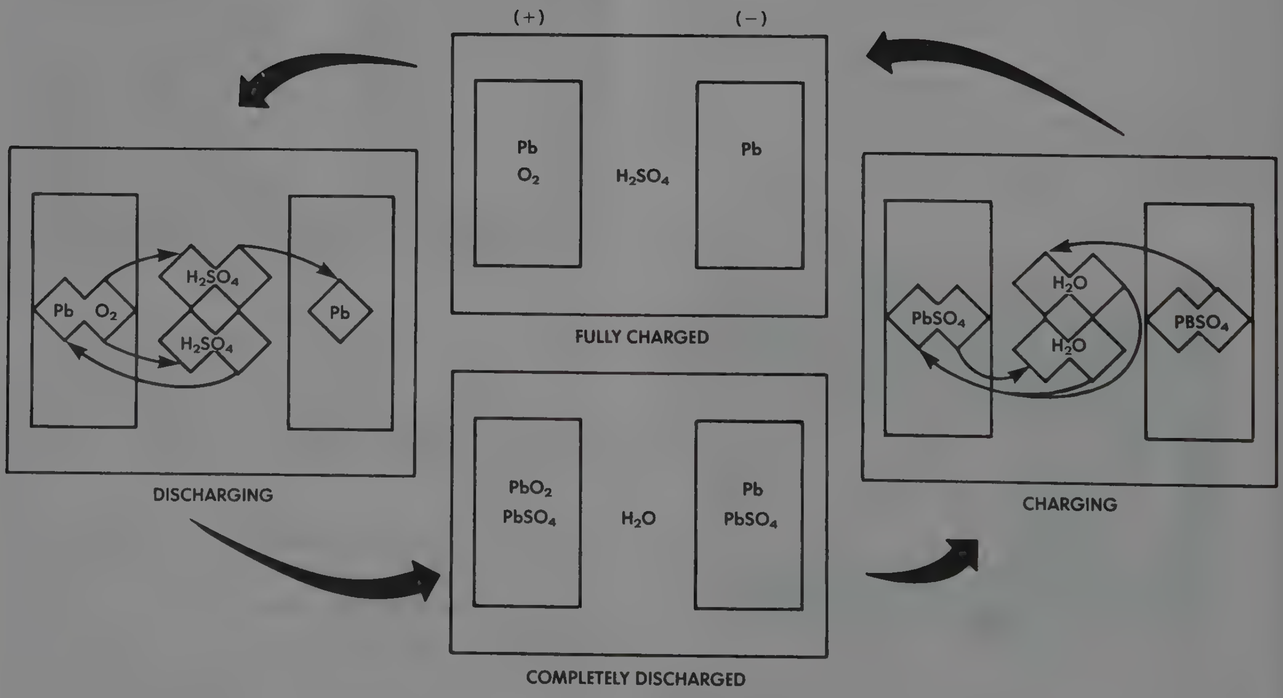


Figure 8-11. Chemistry of a battery illustrated during charging and discharging.

A similar reaction takes place at the negative (−) plate while the electrolyte is reacting with the positive (+) plate. The lead (Pb) of the negative active material combines with the sulfate to form lead sulfate ($PbSO_4$).

As the discharge continues, both plates tend to become more alike, or less dissimilar in composition. This accounts for the loss in voltage, since potential (electrical pressure) depends on the difference between the two materials plus the amount of acid concentration of the electrolyte. As the plates become more alike, the active material of the electrolyte causes a reduction in its specific gravity. The reduction in the specific gravity of the electrolyte provides an accurate and convenient method for determining the battery's *state of charge*, which is covered in Unit 10.

The chemical reversibility *or* the battery's ability to accept a charge (thus restoring it to an almost new condition) is its most valuable asset. The chemical reactions that take place within the battery during the *charge cycle* are basically the reverse of those that occur during the *discharge cycle*. The accumulated lead sulfate on the plates is converted back into electrolyte by the action of the charging device (alternator). The lead sulfate of both plates is split up into its original form of lead (Pb) and sulfate (SO_4), while water is broken down into hydrogen (H_2) and oxygen (O). As the sulfate leaves the plates, it combines with the hydrogen and is restored to sulfuric acid (H_2SO_4). During this process, the oxygen combines with the lead of the positive (+) plate to form lead peroxide (PbO_2). The specific gravity of the electrolyte therefore increases during charge, because sulfuric acid is formed and water is broken down into a gaseous form.

Key Switch

The **key switch**, or *ignition switch*, is a multipurpose control device. Its main function is to control the ignition circuit, but it also controls the starting system as well as the power for the instruments and vehicle accessories. Two types of ignition switches are in use: (1) a *rotating contact* type, which is directly operated by the ignition key and physically located in the instrument panel; and (2) a *steering wheel lock* type, which is usually mounted on the steering column and operated remotely from the *ignition key* through a *linking rod* (Figure 8-12). With this type of assembly, the appropriate connections are made by means of contacts that slide as the key is rotated to the desired position — OFF, ACCESSORY, ON, or START.

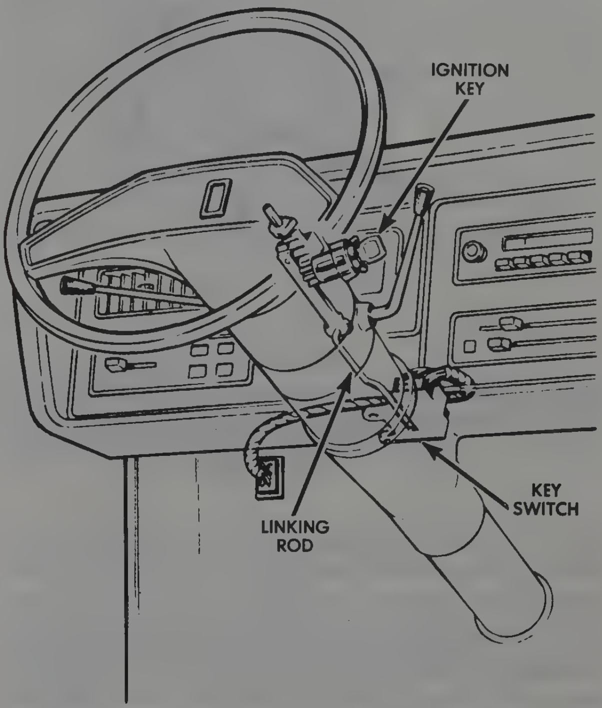


Figure 8-12. Typical steering wheel lock type of key switch assembly. (Courtesy of Ford Motor Company)

Starter Motor

The starter motor is a compact but very powerful direct-current electric motor designed to crank the engine fast enough for the engine to start and continue to run. The *pinion gear* rotates the engine crankshaft by means of teeth that engage mating teeth on the *flywheel ring gear* when the starter motor is actuated. Although starter motors are generally quite similar, starter drive assemblies differ in design.

Motor Principle. The principle of operation for a starter motor is called the **motor principle**. This principle can be demonstrated by a straight-wire conductor located in the magnetic field of a horseshoe-shaped magnet (Figure 8-13). With current flowing through the conductor, there will be two separate magnetic fields — the one produced by the horseshoe-shaped magnet and the one produced by the current flow through the conductor.

Since the magnetic lines of force always leave a north pole and enter a south pole, the direction

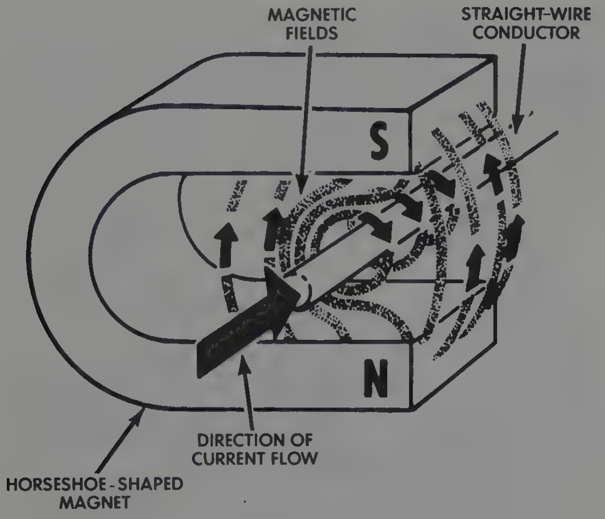

MAGNETIC FIELDS
STRAIGHT-WIRE CONDUCTOR
S
N
DIRECTION OF CURRENT FLOW
HORSESHOE-SHAPED MAGNET

Figure 8-13. Magnetic fields of a horseshoe-shaped magnet and straight-wire conductor. (Courtesy of Chevrolet Motor Division, General Motors Corporation)

of the magnetic lines of force between the two poles of the horseshoe-shaped magnet will be upward (as shown in Figure 8-13). The conductor's magnetic field is shown in the figure as circles around the wire. The net result is more magnetic lines of force on the left-hand side of the wire than on the right. With a strong field on one side of the conductor, and a weaker magnetic field on the other side, the conductor will move from the *strong field* to the *weak field*, or from left to right (Figure 8-14).

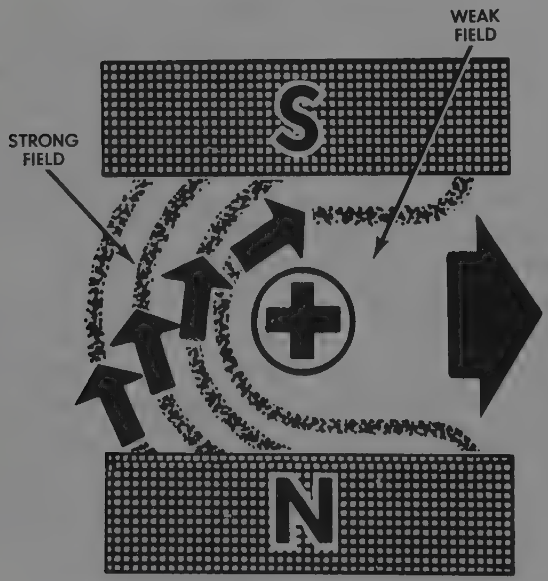

WEAK FIELD
STRONG FIELD
S
N

Figure 8-14. The strong magnetic field on the left pushes the conductor to the right. (Courtesy of Chevrolet Motor Division, General Motors Corporation)

The basic parts of a motor are shown in Figure 8-15. A *wire loop* is placed between two iron pole pieces, one a *north pole* and the other a *south pole*. The wire loop is then connected to two separate commutator bars. Riding on the *commutator bars* are two *brushes*, on connected to the *battery* and the other connected to the *windings* around the iron pole pieces.

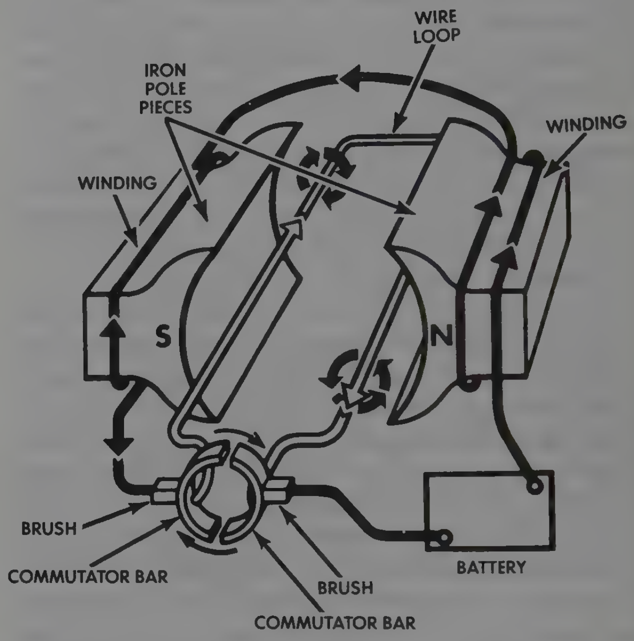

WIRE LOOP
IRON POLE PIECES
WINDING
WINDING
S
N
BRUSH
COMMUTATOR BAR
BATTERY
BRUSH
COMMUTATOR BAR

Figure 8-15. Basic parts of a motor. (Courtesy of Chevrolet Motor Division, General Motors Corporation)

Current flow can be traced from the battery through the windings, to a brush and commutator bar, through the wire loop to the other commutator bar and brush, and then back to the battery. The magnetic fields create a turning, or rotational, effect in the clockwise direction as shown in Figures 8-15 and 8-16.

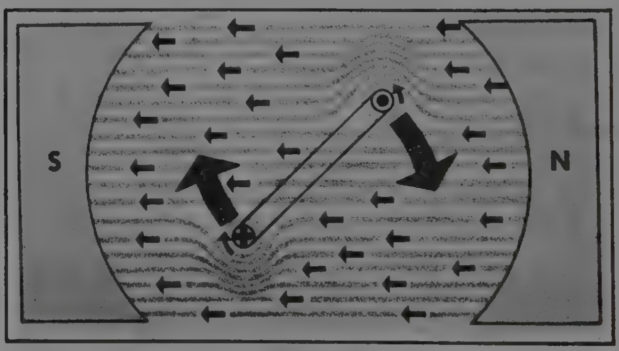


Figure 8-16. Magnetic field rotational effect. (Courtesy of Chevrolet Motor Division, General Motors Corporation)

Starter Motor Construction. The parts of a typical starter motor are contained in a three-piece assembly (*center housing, drive housing,* and *end frame*), shown in the cross-sectional view in Figure 8-17. The tubular center housing contains the *pole shoes* and *field windings*. Attached to the center housing at one end is the drive housing. The end frame is placed at the opposite end. *Bearings* or *bushings* in the end frame and drive housing support the *armature*. The bearings are made from a porous bronze alloy which retains oil. Long *thru-bolts* hold the three-piece assembly together.

Sliding contacts called *brushes* ride on the *commutator* and direct full battery current into the armature. The brushes, usually made from various alloys of copper, provide good electrical contact. They are held in place over the commutator by *brush holders* attached to the end frame. A small spring attached to the brush holder pushes the brushes firmly against the commutator. Wires attached to the brushes direct current into and out of the armature. A *cover band* around the end frame allows for brush inspection.

The field windings and pole shoe form an assembly which is mounted to the center housing by *flat-head machine screws*. The field windings are protected by an insulation wrapping. The field windings and the brushes are connected electrically to a *terminal* which is usually located at the top rear of the center housing. Various wiring arrangements are used.

The armature is an assembly (Figure 8-18) of several parts. Each of the *windings* is held in place by a *laminated iron core*. The laminated iron core consists of thin iron plates. These plates, or laminations, are insulated with thin sheets of paper or special insulation varnish. The laminated iron core helps concentrate and

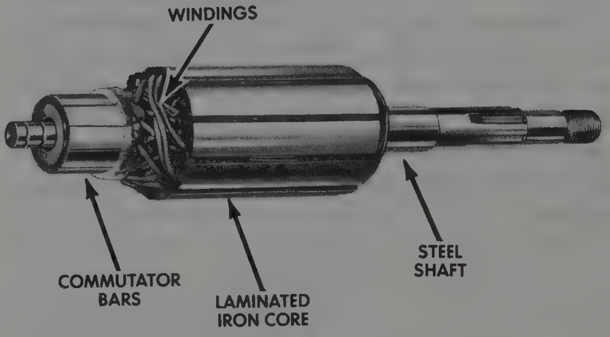

WINDINGS
COMMUTATOR BARS
LAMINATED IRON CORE
STEEL SHAFT

Figure 8-18. Parts of an armature assembly. (Courtesy of Delco Remy, Division of General Motors Corporation)

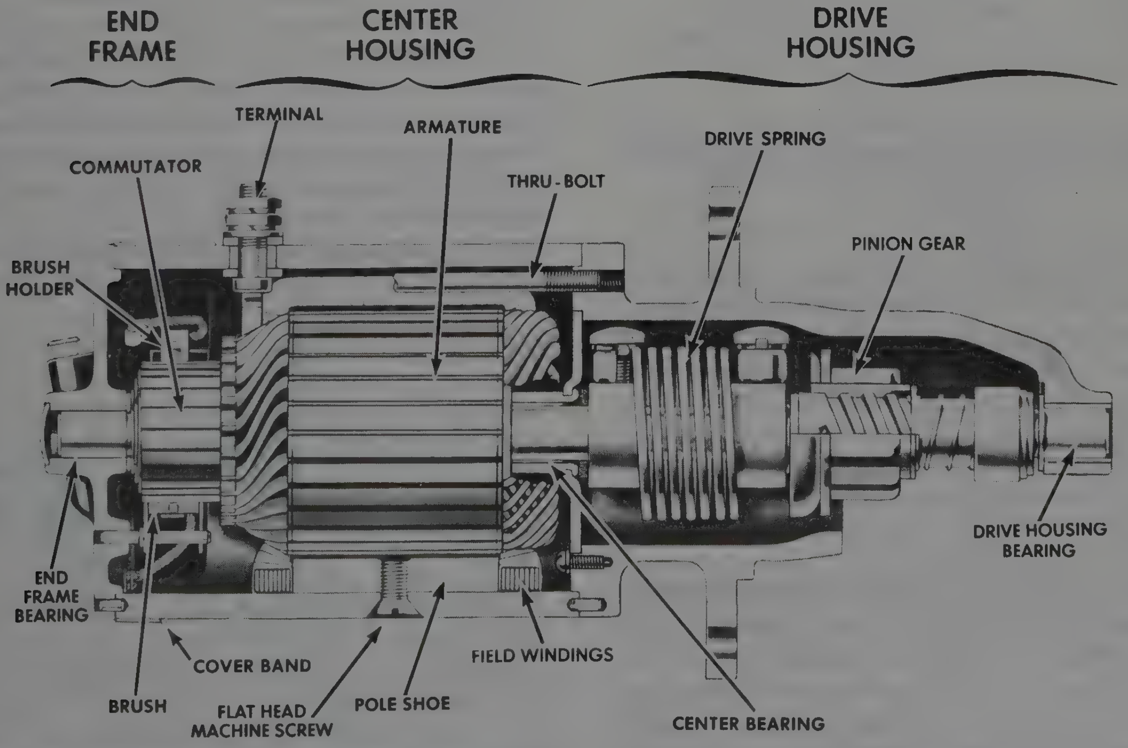

END FRAME
CENTER HOUSING
DRIVE HOUSING
TERMINAL
ARMATURE
COMMUTATOR
THRU - BOLT
DRIVE SPRING
BRUSH HOLDER
PINION GEAR
DRIVE HOUSING BEARING
END FRAME BEARING
COVER BAND
FIELD WINDINGS
BRUSH
FLAT HEAD MACHINE SCREW
POLE SHOE
CENTER BEARING

Figure 8-17. Cross section of a typical starter motor. (Courtesy of Delco Remy, Division of General Motors Corporation)

direct the magnetic lines of force.

The windings are connected to *commutator bars* and are insulated from each other with a material called *mica*. The commutator bars are constructed of a good conductor, usually copper. A hardened *steel shaft*, pressed through the iron core laminations, supports the armature in the three-piece housing assembly. The windings and commutator are insulated from the shaft.

Starter Drives. The rotating armature shaft is used to crank the engine. A starter drive assembly connects the armature shaft to the engine for cranking. It incorporates a small **pinion gear** attached to the end of the starter armature shaft as shown in Figure 8-19. The pinion gear meshes with the **ring gear** on the engine's *flywheel*. When the operator turns the key switch, the starter motor drives the pinion gear, which drives the flywheel and cranks the engine.

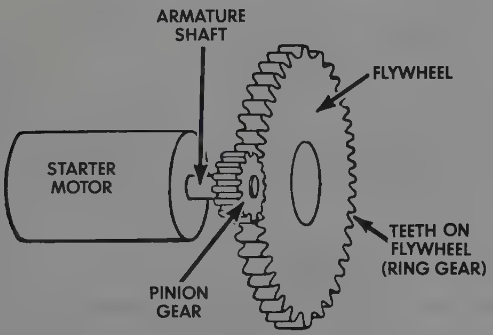


Figure 8-19. A pinion gear attached to the armature shaft drives the engine flywheel. (Courtesy of Delco Remy, Division of General Motors Corporation)

The gear reduction ratio between the starter motor and the engine must be sufficient to provide enough torque to turn the engine over at cranking speed. There are approximately 15 to 20 teeth on the ring gear for every tooth on the drive pinion gear, which means that the armature will rotate approximately 15 to 20 times for every engine revolution. Thus, to turn the engine over at 100 RPM, the armature must rotate at 1,500 to 2,000 RPM.

If the pinion gear remained meshed with the flywheel ring gear at engine speeds above 1,000 RPM, the armature would be spun at very high speeds. These speeds would damage the armature and the commutator. To avoid this, the starter drive assembly is designed to disengage the pinion gear from the ring gear as soon as the engine begins to operate. There are several variations of starter drive assemblies used to protect starter motors. However, most starter motors use an **overrunning clutch drive** as shown in Figure 8-20. The overrunning cluch drive has a *pinion gear* which moves along the *shaft* to engage the ring gear for cranking. The *overrunning clutch assembly* uses a *shift lever*, operated electrically, to actuate the pinion gear. The pinion gear and overrunning clutch assembly move along the armature shaft to engage or disengage with the ring gear.

The shift lever interlocks with a *collar* which pushes on the pinion gear and overrunning clutch assembly through a clutch spring. When the starter motor is actuated, the overrunning clutch assembly and pinion gear move forward along the armature shaft by the collar and clutch spring. If the teeth of the ring gear and pinion gear do not line up, they will not mesh, and the clutch spring will compress. When the pinion gear begins to rotate, the clutch spring pushes the pinion gear into engagement when the gears are properly aligned. The meshing pinion gear causes the ring gear to turn as the starter motor rotates. When the engine starts, the armature must be protected from overspeeding until the pinion is unmeshed. This is the function of the *overrunning clutch assembly.*

An exploded view of the overrunning clutch assembly is shown in Figure 8-21. It has a *shell* attached to a long hollow shaft called a *sleeve*. The sleeve has *splines* on its inside shaft. The *pinion gear* is positioned inside the shell along with *rollers* and *accordion springs*. The rollers are wedged against the pinion gear and the *tapers* of the *notches* inside the shell. A *collar*

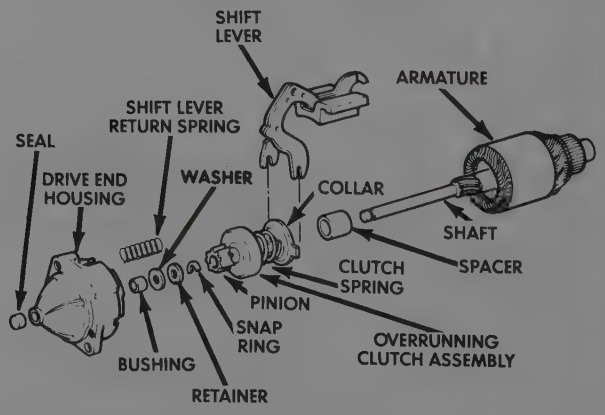


Figure 8-20. Parts of an overrunning clutch drive. (Courtesy of American Motors Corporation)

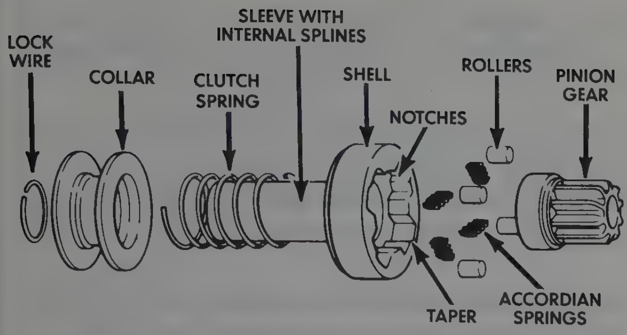

SLEEVE WITH INTERNAL SPLINES
LOCK WIRE
COLLAR
CLUTCH SPRING
SHELL
ROLLERS
PINION GEAR
NOTCHES
TAPER
ACCORDIAN SPRINGS

Figure 8-21. Exploded view of an overrunning clutch assembly. (Courtesy of Delco Remy, Division of General Motors Corporation)

and *clutch spring* are also placed over the sleeve.

Torque is transmitted from the shell to the pinion gear by the rollers. When the engine starts, the flywheel gear drives the pinion gear faster than the armature, and rollers move away from the tapers, allowing the pinion gear to overrun the shell. To avoid prolonged overrunning, the key switch should be opened immediately after the engine starts. When the sleeve is moved back along the armature shaft, the pinion gear moves out of mesh, and the cranking cycle is completed.

Solenoid

The **solenoid** is a magnetic switch mounted on top of the starter motor. It has two important functions: First, it controls the electrical circuit between the battery and starter motor. Second, it shifts the pinion gear in and out of mesh with the ring gear. A cross-sectional view of a solenoid is shown in Figure 8-22.

The solenoid switch has two coils (a *hold-in winding* and a *pull-in winding*) wound around a hollow *cylinder* which contains a movable *plunger*. A *shift lever* is connected to the plunger. The starter motor windings are connected directly to the battery. For cranking, the *contact disc* is pushed into firm contact with the battery and motor terminals (B and M on Figure 8-22) of the solenoid.

The hold-in winding contains many turns of fine wire, and the pull-in winding contains the same number of turns of larger wire. When the *key switch* is closed, current flows from the battery to the solenoid terminals (S and B on Figure 8-22) through the hold-in winding and the ground, and then back to the battery. Current also flows through the solenoid terminal (M) and then through the motor windings to the ground.

All the windings together create a strong magnetism which pulls the plunger into the center of the windings. This action moves the contact disc to close the circuit between the solenoid and the battery teminals. At the same time, the plunger movement moves the shift lever to engage the *collar* of the overrunning clutch assembly, which in turn engages the *pinion* to the flywheel. With the circuit between the battery and starter motor closed, and the pinion now in mesh with the flywheel, the engine is cranked.

The pull-in winding helps the hold-in winding pull the plunger into the core. Once the plunger stops, much less magnetism is needed to hold the plunger in the cranking position. With the contact disc contacting the battery and motor terminals (B and M on Figure 8-22) of the solenoid, the pull-in winding is shorted, and no current flows through it. This design feature reduces current draw on the battery and also reduces the amount of heat created in the solenoid.

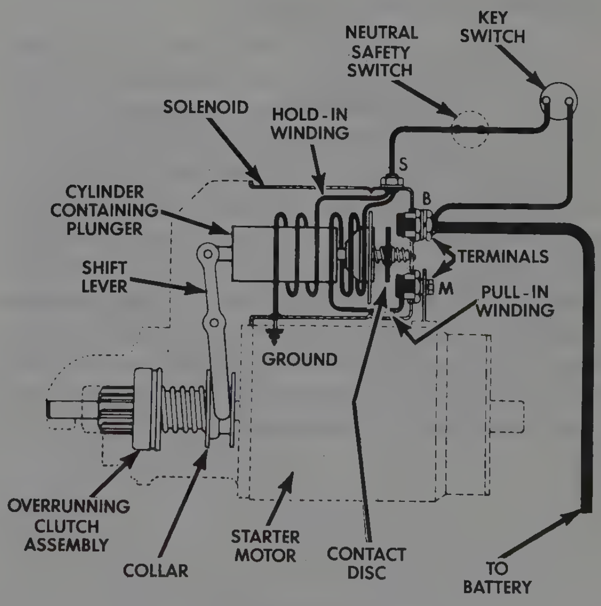

KEY SWITCH
NEUTRAL SAFETY SWITCH
SOLENOID
HOLD-IN WINDING
S
B
CYLINDER CONTAINING PLUNGER
TERMINALS
SHIFT LEVER
M
PULL-IN WINDING
GROUND
OVERRUNNING CLUTCH ASSEMBLY
COLLAR
STARTER MOTOR
CONTACT DISC
TO BATTERY

Figure 8-22. Cross section of a solenoid. (Courtesy of Chevrolet Motor Division, General Motors Corporation)

When the key switch is released, current flows very briefly through the contact disc to the solenoid motor terminal (M), through the pull-in winding in *reverse direction* to the solenoid terminal (S), and then through the hold-in winding in a *normal direction* back to the battery. The magnetism created by one winding opposes and cancels out the magnetism created by the other. The return spring in the cylinder moves the entire shifting mechanism to the at-rest position. This completes the cranking cycle.

Neutral Safety Switch

All cars equipped with automatic transmissions and many with manual transmissions have a device to prevent the engine from being started in gear. Without this device, the car would lunge forward (or backward) if mistakenly started in gear, possibly causing an accident. This device is a **neutral safety switch** in the starting system circuit. It is mechanically opened when the transmission shift lever is moved to any position other than NEUTRAL or PARK. Column-mounted shift levers have a blocking device to mechanically prevent starting when the lever is in DRIVE or REVERSE. The typical position of a neutral safety switch is shown in Figure 8-22.

Starting System Wiring

The starting system actually consists of two separate but related circuits: the *starter control circuit* and the *motor feed, or power supply, circuit*. The starter control circuit includes the starting portion of the ignition (key) switch, the neutral safety switch (if one exists), and the light-gage wire included in the wiring harness that connects these components to the solenoid. The motor feed circuit consists of heavy-gage cable from battery to solenoid to starter motor. The heavy cable carries the high current required to operate the starter motor with minimal loss from internal resistance.

KEY TERMS

Active material: Sponge lead and lead peroxide used in the plates of a battery.

Cell: A basic component of the battery, capable of developing about 2 volts.

Electrolyte: The acid solution of water and sulfuric acid in a battery cell.

Key switch: A multi-purpose control device whose main function is to control the ignition circuit.

Lead peroxide: The active material that makes up the positive (+) plate.

Maintenance-free battery: A battery that does not have cell caps for periodic refilling with water.

Motor principle: The principle of operation for a starter motor.

Negative plates: In a battery, the group of plates negatively charged.

Neutral safety switch: A switch used to prevent starting unless the transmission is in NEUTRAL or PARK.

Overrunning clutch drive: A type of starter motor drive that uses an overrunning clutch to disconnect the drive pinion from the flywheel.

Pinion gear: The gear driven by the starter motor to rotate the flywheel.

Positive plates: In a battery, the group of plates that gives off electrons.

Ring gear: The gear formed by the teeth on the outside of the flywheel.

Separators: Sheets of insulation placed between the plates of a battery.

Solenoid: A magnetic switch used to control the electrical circuit between the starter motor and battery. It also shifts the pinion gear in and out of mesh with the ring gear.

Sponge lead: The active material that makes up the negative (−) plate.

SELF-CHECK

1. List the main parts of the starting system.
2. Describe how positive (+) and negative (−) plates in an acid solution can cause a voltage.
3. List the main parts of a battery cell.
4. What is the difference between an element and a cell?
5. How are battery cells connected together to get 12 volts?
6. List the four chemical ingredients in an automotive battery.
7. List the three purposes of the key switch.
8. Explain the motor principle.

9. List the main parts of an armature.
10. What is the purpose of the brushes?
11. Why does the starter motor need an overrunning clutch drive?
12. Describe how the overrunning clutch drive works to mesh and unmesh the pinion gear with the ring gear.
13. What are the two main functions of the solenoid?
14. Why does the solenoid have two windings?
15. What is the purpose of the neutral safety switch?

DISCUSSION TOPICS AND ACTIVITIES

1. Build a basic battery cell, and use a sensitive voltmeter to measure the voltage.
2. Use a horseshoe-shaped magnet and a conductor to demonstrate the motor principle.

CERTIFICATION PRACTICE

1. The negative (−) plate of a battery is made of:
   A. Sponge lead
   B. Lead peroxide
   C. Either A or B
   D. Neither A nor B
2. A cell consists of:
   A. Plates
   B. Separators
   C. Acid
   D. All of the above
3. The starter drive assembly:
   A. Connects and disconnects the pinion gear from the flywheel's ring gear
   B. Prevents the flywheel from driving the starter motor armature
   C. Both A and B
   D. Neither A nor B
4. The solenoid is used to:
   A. Control the electrical circuit between the battery and starter motor
   B. Shift the pinion gear in and out of mesh with the ring gear
   C. Both A and B
   D. Neither A nor B
5. The solenoid plunger is pulled into position by the:
   A. Pull-in winding
   B. Hold-in winding
   C. Both A and B
   D. Neither A nor B

ANSWERS

1:A, 2:D, 3:C, 4:C, 5:C

Unit 9

CHARGING SYSTEM OPERATION

The purpose of the charging system is to provide the electrical energy needed to charge the battery and to power all the electrical components and systems on the automobile. When the engine is not running, the battery provides this electrical energy. When the engine is running, the charging system takes over. Since the ignition system depends upon proper operation of the charging system for its power source, the tune-up technician must understand the parts and operation of the charging system. This unit explains the operation of the charging system and its components.

DEVELOPING JOB COMPETENCIES

When you finish reading and studying this unit, you should be able to:

- List and describe the main components of the charging system.
- Explain how magnetism is used to generate electricity.
- List and describe the main parts of the alternator.
- Explain the operation of a diode.
- Explain how current and voltage are limited in an alternator.
- Explain how a voltage regulator works to limit alternator voltage.

CHARGING SYSTEM COMPONENTS

The basic parts of a charging system are shown in Figure 9-1. The **alternator**, which is the heart of the charging system, is an alternating-current generator mounted on the engine and driven by a belt from the crankshaft. The alternator develops alternating current, which is changed to direct current. **Alternating current** is current that changes from positive (+) to negative (−) at a regular cycle. **Direct current** is current that does not change from positive (+) to negative (−).

A *voltage regulator*, either inside or outside the alternator, senses the electrical needs of the vehicle and adjusts the output of the alternator accordingly. An *indicator light* on the instrument panel allows the driver to observe whether the system is operating properly. The indicator light circuit is fed through the *key switch*. The *battery* is connected electrically to the alternator, so that either one may supply the electrical needs, and so that the alternator can charge the battery.

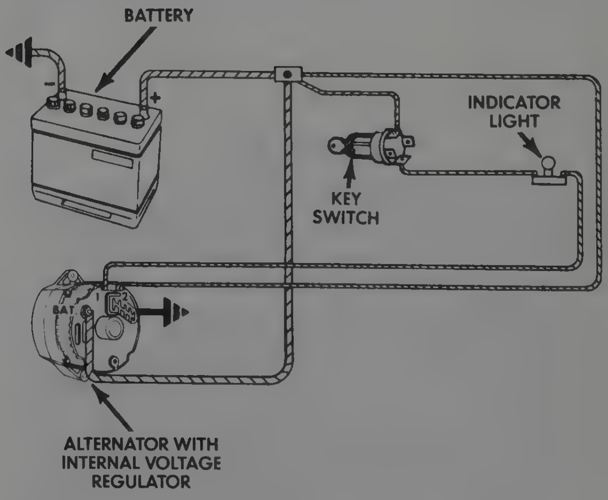


Figure 9-1. Pictorial wiring diagram showing the basic parts of a charging system. (Courtesy of Chevrolet Motor Division, General Motors Corporation)

GENERATING ELECTRICITY

Electricity is generated by an alternator using the principle of *electromagnetic induction*. Anytime a wire (conductor) is moved through a magnetic field, or a magnetic field is moved past a wire, the magnetic lines of force are cut, and a voltage is developed in the wire. When this wire is connected to an external circuit, current can flow as shown in Figure 9-2. The direction of the *flow of current* in the wire depends upon whether the relative motion of the wire is *up* or *down* in the magnetic field. The amount of voltage generated depends upon the number of magnetic lines of force that are cut, the number of turns of the wire, and the speed at which the wire passes through the magnetic lines of force.

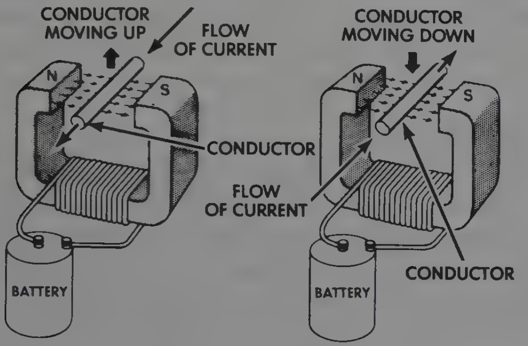


Figure 9-2. Developing electricity through electromagnetic induction. (Courtesy of Chrysler Corporation)

If a *permanent magnet* is rotated inside a *wire loop* (conductor) so that *lines of force* cut across the conductor, a voltage is induced that causes a current to flow through the completed circuit (Figure 9-3). When the north pole is at the top and the south pole is at the bottom, the flow of current is from A to B in Figure 9-3. However, if the permanent magnet is rotated 180°, the south pole will be at the top and the north pole at the bottom (Figure 9-4). During this part of the cycle, the lines of force are cutting the conductor in the opposite direction, and the voltage induced will cause current to flow from B to A in Figure 9-4. In other words, current will flow through the external circuit, first in one direction and then in the other (Figure 9-5). The direction of current flow will reverse every half-revolution. The output is described as *alternating current* because of the alternating directions of the current.

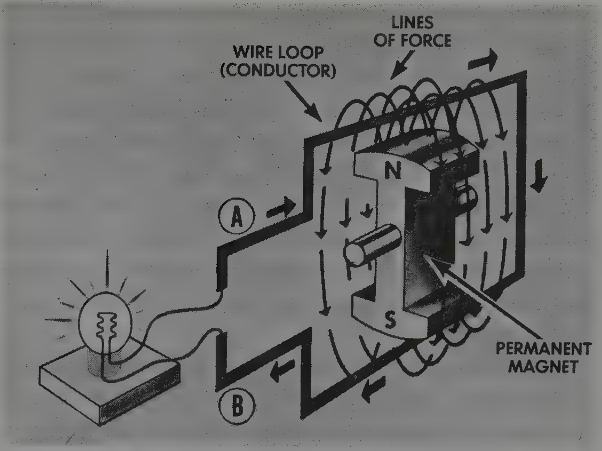


Figure 9-3. Current flow with the north pole of the magnet at the top. (Courtesy of Chrysler Corporation)

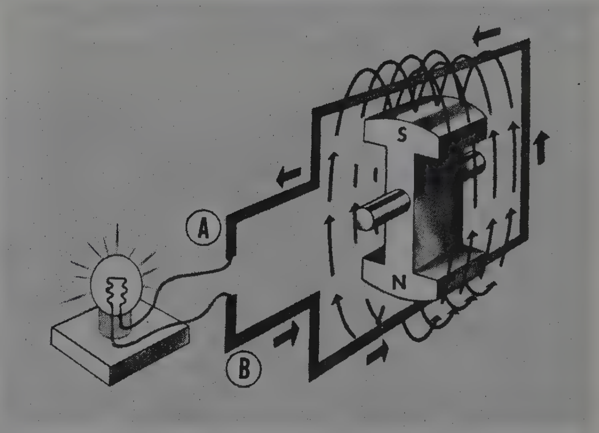


Figure 9-4. Current flow with the south pole of the magnet at the top. (Courtesy of Chrysler Corporation)

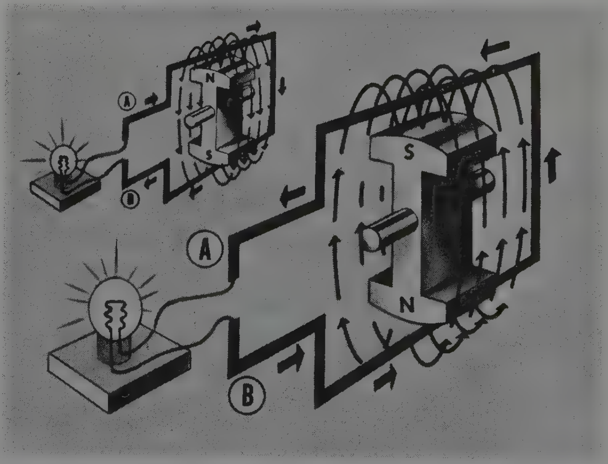


Figure 9-5. The direction of current flow reverses every half-revolution of the permanent magnet. (Courtesy of Chrysler Corporation)

The output of an alternator would be difficult to control if we could not control the strength of the rotating magnetic field. In Figure 9-6, the rotating permanent magnet has been replaced by an electromagnet called the **rotor**. The rotor core, or pole piece, is wound with wire and connected to an *external power source* of direct current through two *slip rings* and two *brushes*. This arrangement is a simplified version of the externally excited (energized) rotor field used in most alternators.

The stationary conductor, represented by a single loop of wire, forms the **stator** of the alternator. Since the rotor pole piece is externally excited by direct current, one pole will always be north and the other south. Current flow through the conductor, or stator loop, will reverse its direction every half-revolution. The simple alternator illustrated in Figures 9-3 through 9-6 is described as a two-pole, externally excited, single-phase AC generator.

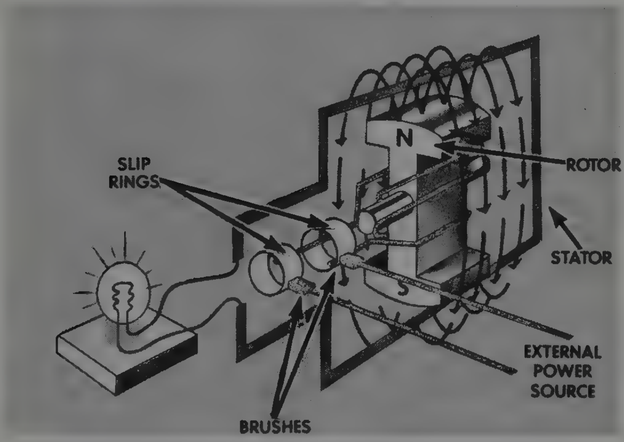


Figure 9-6. The rotor is connected to an external power source. (Courtesy of Chrysler Corporation)

ALTERNATOR CONSTRUCTION

The simple alternator illustrated in Figures 9-3 through 9-6 would not develop enough current for a vehicle's electrical needs. Additional parts are necessary. The major parts of an alternator (Figure 9-7) are the *two end frames* (or *housings*), the *stator*, the *rotor*, the *brushes*, and the *diode assembly*.

The front and rear housings must be made of a light, non-magnetic material. Die-cast aluminum is used for this. The front housing permits mounting the alternator on the engine. The rotor is supported by *bearings* in the front and rear housings. The front bearing is slip fit into the housing and is held in place by a spring-steel *retainer*. The rear housing supports and houses the diode assembly and has provisions for the necessary wire terminals. A rear bearing is press fit into the rear housing.

The stator is an assembly (Figure 9-8) which is held in place between the front and rear housings. A number of steel stampings are riveted together to form the *core* of the stator. Three separate series of *coils* are wound around the *stator teeth*. These coils are arranged in three layers in each stator slot with their relative positions staggered. One end of each winding (series of coils) is connected to a *stator lead terminal*. The other ends of the three windings are joined together. This junction is referred to as the *neutral junction* or *Y connection* and is connected to a blade-type terminal in the rear housing.

Since the three windings are staggered, the current produced in each winding is staggered, or "out of phase," with the other windings. The use of three windings makes the alternator a three-phase type. The manner in which the three windings are connected together (at the neutral junction) makes the stator a *Y-type*.

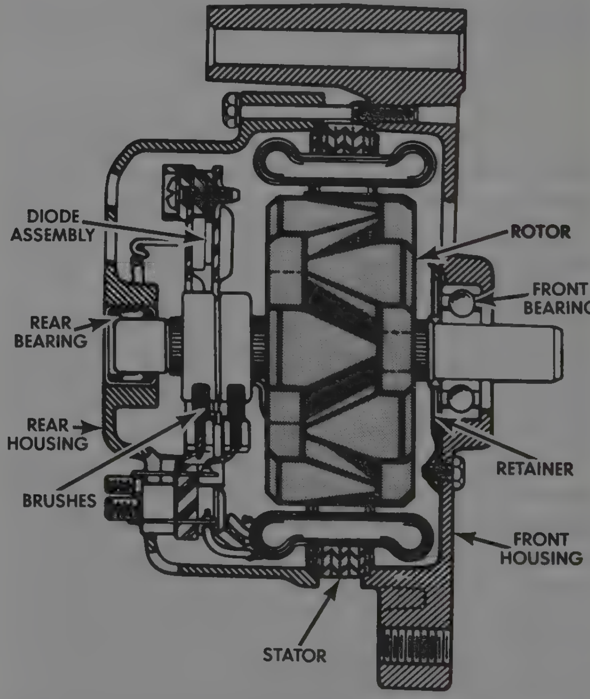


Figure 9-7. Cross section of an alternator. (Courtesy of Ford Motor Company)

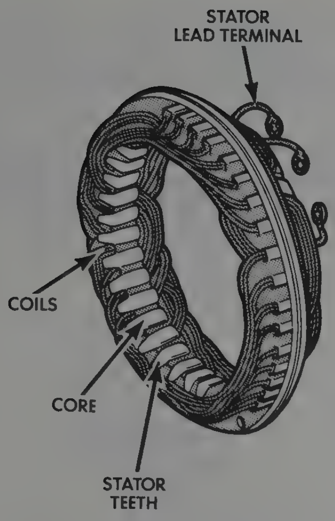


Figure 9-8. Parts of a stator. (Courtesy of Chrysler Corporation)

The rotor is an assembly that consists of a *shaft*, a *coil*, two *pole pieces* (*magnetic poles*), and *slip rings* (Figure 9-9). The two pole pieces, with six malleable iron *fingers*, are located at each end of the coil. The pole pieces are positioned so that the fingers mesh but do not touch. The pole pieces are pressed on the shaft. When the magnet is energized with a direct current, the fingers become alternately north and south magnetic poles. The slip rings form an assembly which is pressed onto the rear of the shaft and is connected to the magnet winding. Direct current is supplied to the coil through the slip rings. The vehicle's fan and pulley assembly is attached to the end of the rotor shaft.

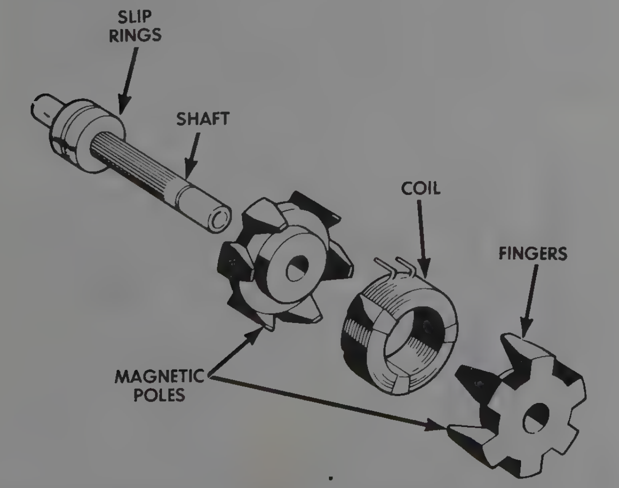


Figure 9-9. Parts of a rotor. (Courtesy of Ford Motor Company)

Brushes, mounted in a *brush holder assembly*, are held against the slip rings by a coil spring located at the pivot end of each of the two *brush holder arms* (Figure 9-10). The brush holder arms are split, or fork-shaped, and hold the brushes by side pressure. Plastic parts are used in brush mounting to obtain a nonsticking operation in the presence of a corrosive atmosphere. Each brush has a flexible copper lead wire or pigtail to assure good electrical connections. One brush is insulated from ground and is called the *insulated brush*. The other brush is connected to ground and is called the *gounded brush*.

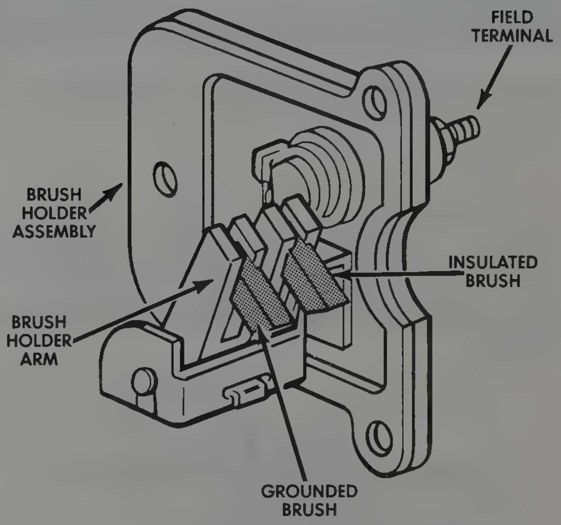


Figure 9-10. Brushes are mounted in a brush holder assembly. (Courtesy of Ford Motor Company)

DIODE OPERATION

The current developed in the stator is alternating current. It must be changed or rectified to direct current before it can be used in the car's electrical system. Changing alternating current to direct current is the job of the *diode assembly* (Figure 9-7) mounted in the *rear housing* of the alternator.

A **diode** is a solid state electronic component which changes, or rectifies, alternating current to direct current by allowing current to pass through it freely in one direction but not in the other direction. It acts like a check valve on an electrical system, in the same way a mechanical check valve operates in a hydraulic system (Figure 9-11).

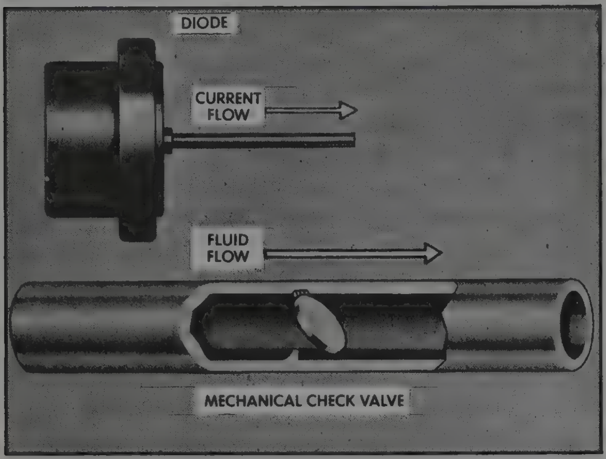


Figure 9-11. A diode can be likened to a mechanical check valve. (Courtesy of Chevrolet Motor Division, General Motors Corporation)

The diode symbol and action is shown in Figure 9-12. The arrow points in the direction of current flow. The vertical bar represents a wall that blocks current from flowing in the reverse direction.

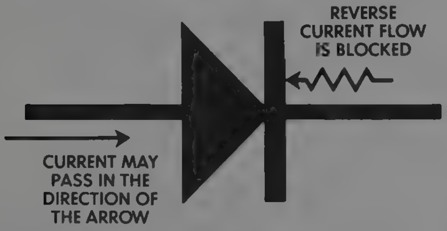

REVERSE CURRENT FLOW IS BLOCKED
CURRENT MAY PASS IN THE DIRECTION OF THE ARROW

Figure 9-12. This symbol for a diode shows the direction of current flow. (Courtesy of Chevrolet Motor Division, General Motors Corporation)

A cross-sectional view of a diode is shown in Figure 9-13. A thin *silicon wafer* is positioned at the bottom of the diode *case*. The heavy case walls protect the delicate silicon wafer and act as a *heat sink* to dissipate the heat produced by current flow. The diode is tightly sealed to prevent any entry of moisture.

The function of a diode is to permit current flow in the circuit in only one direction and to block it from flowing in the opposite direction. This is made possible by the electrical characteristic of the silicon wafer within the heat sink. When the diode is constructed with the silicon wafer placed in one direction, current will flow through the diode when positive (+) voltage is connected to the diode lead or terminal and a negative (−) voltage is connected to the diode case. When the position of the silicon wafer is reversed and the same connections are made, no current will flow and the circuit is blocked. The diode, therefore, acts as a check valve, allowing current flow in only one direction.

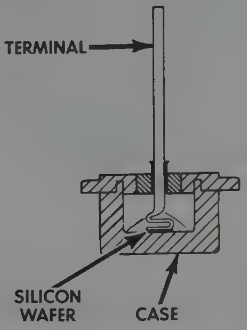


Figure 9-13. Cross section of a diode. (Courtesy of Chrysler Corporation)

Six diodes are mounted in the rear housing of the alternator. These diodes when connected serve as a diode assembly (rectifier) that changes the alternating voltages developed in the stator windings to a single unidirectional voltage (Figure 9-14). Therefore, unidirectional voltage appears at the output terminal of the alternator; and, consequently, the alternator supplies direct current to charge the battery and to operate electrical accessories.

The electrical connection of the *diode assembly* to the *stator* is shown in the wiring diagram of Figure 9-15. This type of circuit arrangement provides a smooth flow of direct current (DC) to the *battery* and other accessories connected to the alternator. Also, the blocking action of the diodes prevents battery discharge through the alternator.

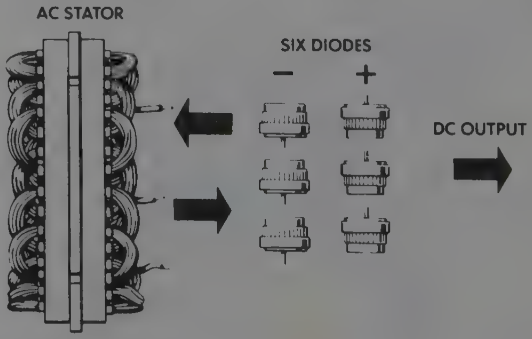


Figure 9-14. The stator is connected to six diodes. (Courtesy of Delco Remy, Division of General Motors Corporation)

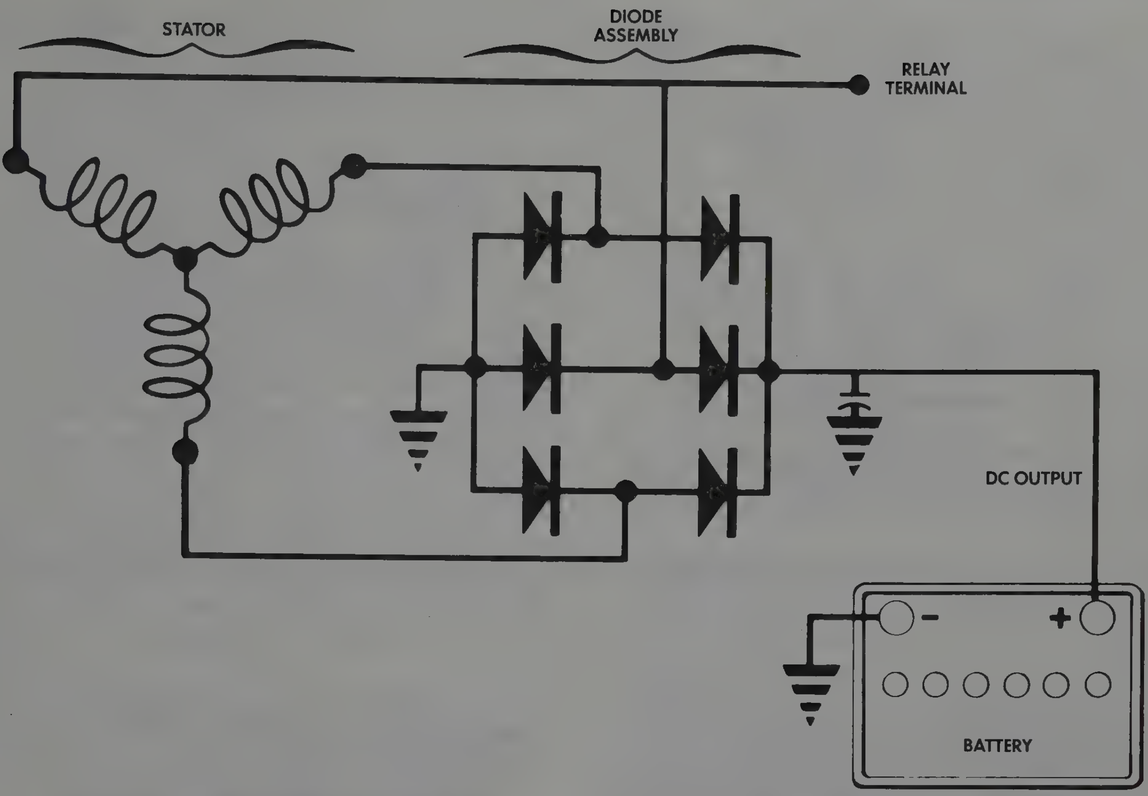


Figure 9-15. Wiring diagram showing how the diodes are connected to the stator. (Courtesy of Delco Remy, Division of General Motors Corporation)

THREE-PHASE OPERATION

As explained under the heading of "Alternator Construction," the stator has three separate windings. One end from each winding is connected to a common junction. This is called a Y connection or neutral junction, and the alternator is referred to as a three-phase, Y-connected stator (Figure 9-16). A *phase* is an electrical term for the period of time in which a particular winding is developing current. The output of the alternator is taken off the other end of each of the three windings.

The output from each of the three windings can be shown as a graph of changing (reversing) voltages, or pulse waves (Figure 9-17). Three of the reversing pulse waves can be used to illustrate the output of a three-phase alternator. The output of each phase overlaps, but does not coincide with, the other two. The overlapping of the three phases smooths out (closely maintains) the total flow of current from the stator windings. However, half of the total output is still in one direction and the other half is in the opposite direction.

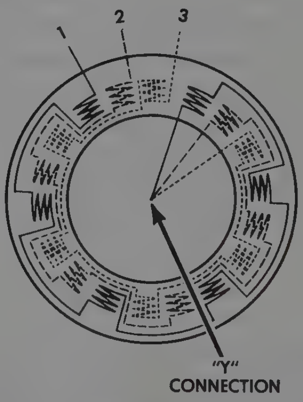


Figure 9-16. Three-phase, Y-connected stator. (Courtesy of Chrysler Corporation)

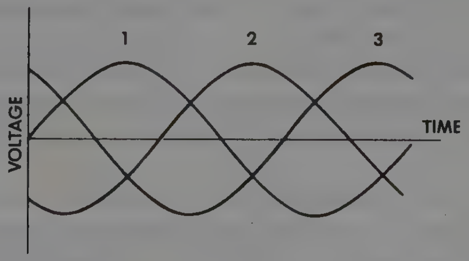


Figure 9-17. Voltages (numbered 1, 2, and 3) induced in the stator windings. (Courtesy of Chrysler Corporation)

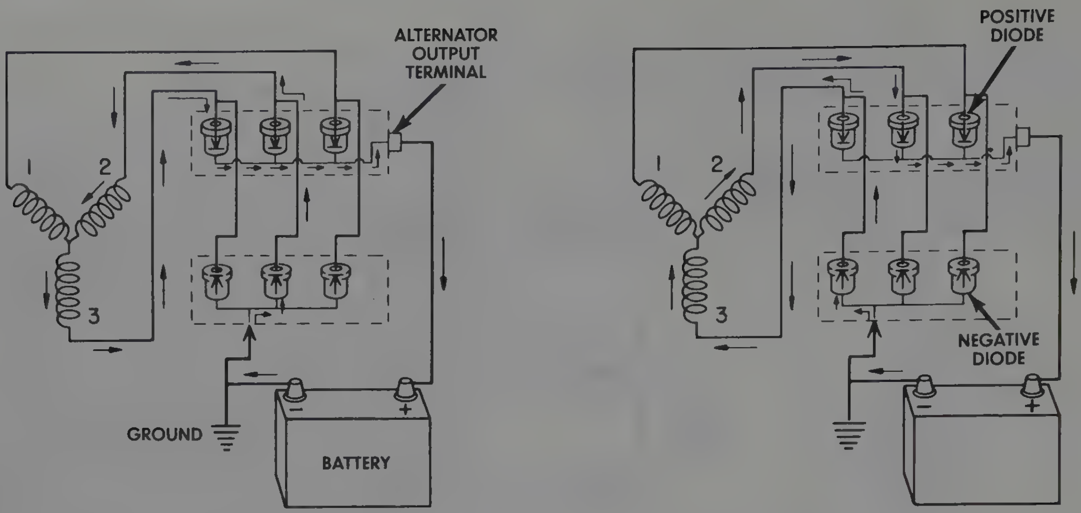


Figure 9-18. The three-phase stator and diodes provide full-wave rectification. (Courtesy of Chrysler Corporation)

When three negative (−) diodes and three positive (+) diodes are connected to the stator as shown in Figure 9-18, the current output from the alternator to the battery will be in only one direction (direct current). Two of the several possible conditions for current output are also shown in Figure 9-18. Regardless of the direction of the current developed in the stator, current will always enter the positive (+) terminal of the battery and return to the stator through the negative (−) terminal of the battery. Since the current output of all stator phases is converted to direct current (DC) in the same way, the entire output is converted to direct current.

CURRENT LIMITING

The automotive electrical system must be protected against a current flow or voltage that is too high. The current developed by an alternator is self-limiting. That is, the construction and operation of the stator coils, or windings, are able to limit current to safe levels. Therefore, there is no need for an external current-limiting device.

In order to understand how the stator coil is able to self-limit current, remember the concept presented earlier in Unit 3. Current flowing through a coil of wire produces a magnetic field. When the current flowing through a coil is an alternating current, the magnetic field produced around the coil will:

- Build up and establish a polarity.
- Fall off as current flow decreases.
- Build up again when the direction of current flow is reversed — but the polarity of the magnetic field will be reversed.
- Decrease as current flow decreases.

As the current flow through a coil *increases*, each line of force will spread out and cut across the adjacent windings. The direction in which these lines of force cut the adjacent coil winding is such that a voltage will be induced in the coil windings *opposite* to that applied to the coil. This opposing voltage tends to limit the current flowing through the coil windings. Inductive opposition to current flow is called *inductive reactance*.

The higher the frequency of the alternating current flowing in a stator coil, the more rapid the build-up and collapse will be of the induced magnetic field. Increasing the rate of magnetic field build-up increases the speed at which the lines of force cut through the windings. This in turn increases the inductive reactance opposing the current flow through the windings of the stator coil producing the magnetic field.

VOLTAGE CONTROL

Unlike current, voltage can become excessive inside an alternator. The main factors causing voltage to increase are:

- Increased speed of motor.
- Increased strength of the rotor's magnetic field.
- Increased number of turns of wire in the stator winding, resulting in more conductors being cut by the lines of force from the rotor.

The voltage output of the alternator is controlled by a **voltage regulator**, which controls current flowing through the field coil of the *rotor* (Figure 9-19). System voltage is applied to the *ignition* (IGN in the figure) terminal of a voltage regulator through the *key switch*. Field current is controlled by the voltage regulator and delivered through the *field* (FLD in the figure) terminal of the voltage regulator to the insulated brush and slip ring. The field circuit is completed by grounding the other end of the field coil through the grounded brush and its slip ring.

All late-model vehicles use a transistorized, electronic voltage regulator, which is mounted either outside or inside the alternator.

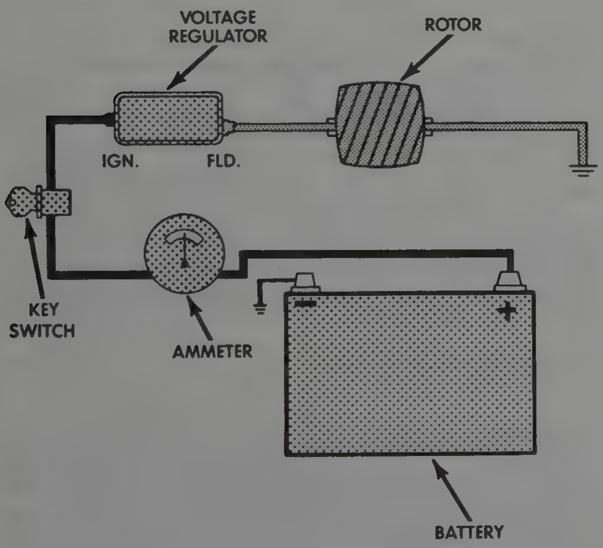


Figure 9-19. Wiring diagram showing how alternator voltage is controlled by controlling current flow through the field coil of the rotor. (Courtesy of Chrysler Corporation)

TRANSISTORIZED ELECTRONIC VOLTAGE REGULATOR OPERATION

The transistorized electronic voltage regulator (Figure 9-20) controls the alternator output by regulating the alternator field current. The regulation is accomplished electronically with the use of *transistors* and *diodes*. The voltage-sensing component is a *zener diode*, which has the characteristic of suddenly changing its resistance when a specified voltage is reached.

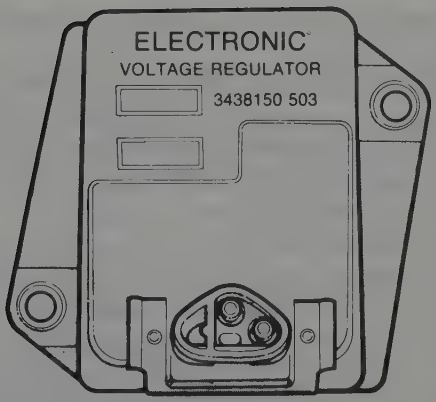


Figure 9-20. The transistorized, electronic voltage regulator controls alternator voltage by regulating the alternator field current. (Courtesy of Chrysler Corporation)

A zener diode operates the same as a rectifying diode to a certain point. It allows current flow in one direction and blocks current flow in the opposite direction, but only until a certain voltage is reached. At that time its resistance to current flow is negligible in both directions. It is therefore said to be *biased* in the direction that it opposes current flow.

The transistor is an electronic switching device used to control a greater current by means of controlling a smaller current. The transistor symbol (Figure 9-21) shows three leads to a common center point. The leads are identified as *emitter* (E), *base* (B), and *collector* (C). These three leads make up two circuits within the transistor. The emitter lead is the input lead, and the base and collector are the output leads of the transistor, so the connection is like a parallel circuit. The two circuits, there-

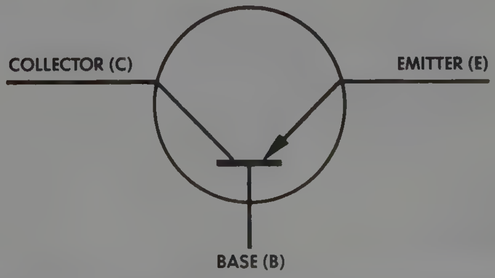


Figure 9-21. Transistor symbol nomenclature. (Courtesy of Chevrolet Motor Division, General Motors Corporation)

fore, are the emitter-base circuit and the emitter-collector circuit.

Only when there is current flow in the emitter-base circuit is there current flow in the emitter-collector circuit. If there is no current flow in the emitter-base circuit, then there is no current flow in the emitter-collector circuit.

If the emitter-base circuit of the transistor can be manipulated to ON or OFF positions, then the emitter-collector circuit (carrying a greater current) can simultaneously be manipulated to ON or OFF. The emitter-collector circuit, therefore, is used in place of the set of contact points used in earlier models of voltage regulators. The emitter-base circuit is the means by which the emitter-collector circuit is controlled. More information on transistors is presented in Unit 11 under the heading of "Transistor Operation."

The main parts of a typical transistorized electronic voltage regulator are shown in Figure 9-22. The wiring diagram for the same regulator is shown in Figure 9-23. When the engine is started, battery current is supplied to the field coil through *bias diode D2* and *power transistor Q2* (see Figures 9-22 and 9-23). The bias diode aids high temperature stability of the power transistor. As the alternator begins to supply current, battery voltage increases. When battery voltage reaches approximately 14.5 volts, *zener diode Z1* suddenly reduces its resistance and turns on the *driver transistor Q1*. When the driver transistor turns ON, the power transistor turns OFF. Battery voltage is reduced slightly, because the alternator output was reduced when the power transistor turned OFF the field current. Zener diode voltage is reduced at the same time as battery voltage, causing the zener diode to increase its resistance and turn OFF the driver transistor. The power transistor is caused to turn ON again, resulting in a complete cycle of events. The transistors alternate in the ON-OFF action. When the driver transistor turns ON, the power transistor turns OFF.

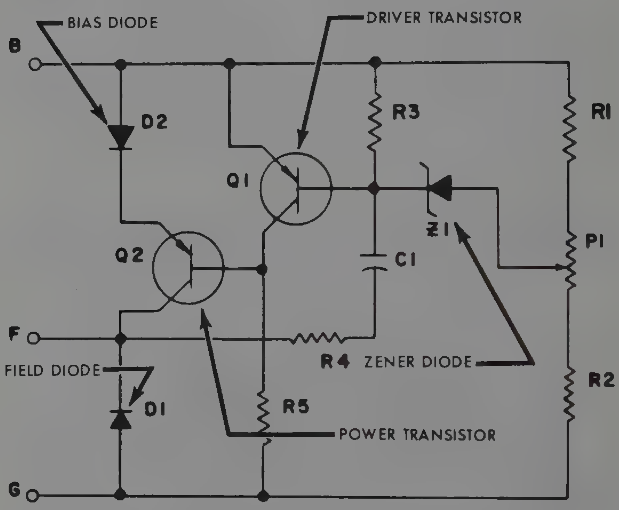


Figure 9-23. Wiring diagram for a typical transistorized voltage regulator. (Courtesy of Ford Motor Company)

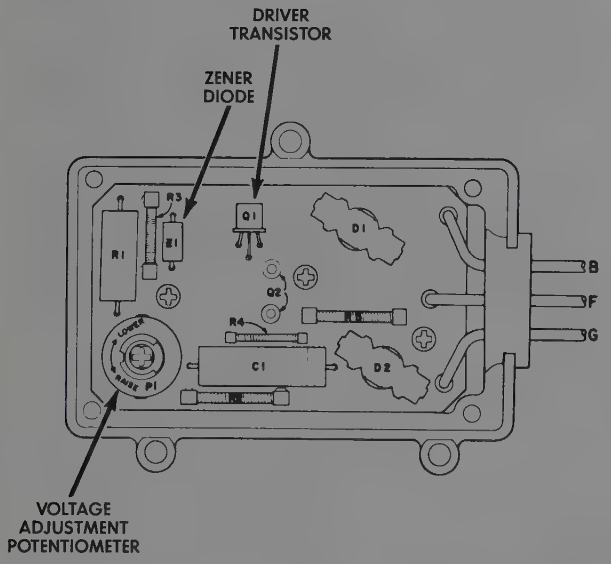


Figure 9-22. Main parts of a typical transistorized electronic voltage regulator. (Courtesy of Ford Motor Company)

The temperature-compensating *resistor R1* is made of a special material that changes its resistance with temperature in such a way that during cold weather, battery-charging voltage is increased.

Transistor regulator calibration can be changed on some regulators by using a screwdriver to adjust *potentiometer P1*. Turning the adjustment screw in the counterclockwise direction usually raises the regulated voltage. *Capacitor C1*, in series with *resistor R4*, causes the driver transistor and the power transistor to switch ON and OFF faster. The remaining resistors in the regulator provide proper operating voltages for the zener diode and the two transistors.

KEY TERMS

Alternator: An engine-driven, alternating-current generator.

Alternating current: Current that changes from positive (+) to negative (−) at a regular cycle.

Diode: A solid state electronic component that changes, or rectifies, alternating current to direct current by allowing current to pass through it freely in one direction but not in the other direction.

Direct current: Current that does not change from positive (+) to negative (−).

Rotor: The rotating electromagnet inside an alternator.

Stator: The three stationary windings in an alternator used to generate a voltage.

Voltage regulator: A charging system component used to limit current flow in the field coil of the rotor and control alternator output.

SELF-CHECK

1. List the basic parts of a charging system.
2. Explain how current can be generated with a magnet and a conductor.
3. List the basic parts of an alternator.
4. Explain the purpose of the brushes inside an alternator.
5. Explain the purpose of the diodes inside an alternator.
6. Why does an alternator stator have three separate windings?
7. How is current limited inside an alternator?
8. What are the main factors that affect the amount of voltage created in an alternator?
9. How is the output of an alternator controlled?
10. How does a voltage regulator work to limit voltage?

DISCUSSION TOPICS AND ACTIVITIES

1. Disassemble an alternator and identify all the components.
2. How is an ohmmeter used to determine the direction of current flow through a diode?

CERTIFICATION PRACTICE

1. Which of the following are main components of the charging system?
   A. Alternator
   B. Storage battery
   C. Voltage regulator
   D. All of the above
2. Which of the following are main components of an alternator?
   A. Rotor
   B. Stator
   C. Diode assembly
   D. All of the above
3. The voltage developed by an alternator is affected by the:
   A. Strength of the rotor's magnetic field
   B. Number of turns in the stator winding
   C. Rotor speed
   D. All of the above
4. Alternator brushes ride on:
   A. Commutators
   B. Stator
   C. Slip rings
   D. Field coils
5. The principles of electromagnetic induction are used by an alternator to generate:
   A. Current
   B. Voltage
   C. Resistance
   D. None of the above

ANSWERS

1: D, 2: D, 3: D, 4: C, 5: A

Unit 10

STARTING AND CHARGING SYSTEM PRECHECKS

Most tune-up and diagnosis procedures require the technician to make a number of prechecks (tests) on the starting and charging systems (the starting system is covered in Unit 8 and the charging system in Unit 9). The ignition system can operate correctly only if it is supplied with enough electrical energy from the battery during cranking and the alternator during driving. A no-start condition might be mistakenly blamed on the engine, fuel, or ignition system, when it is actually caused by a problem in the starting system. The prechecks described in this unit quickly reveal whether the starting and charging systems are operating correctly.

DEVELOPING JOB COMPETENCIES

When you finish reading and studying this unit, you should be able to:

- Visually inspect a battery.
- Measure a battery's specific gravity.
- Load test a battery.
- Perform a starter motor amperage draw test.
- Perform an alternator output test.

BATTERY VISUAL INSPECTION

During cranking, the battery supplies the power required to crank the engine and the power to operate the ignition system. If battery power is low, the engine may crank too slowly to start, or the ignition system may not receive enough power to function.

The first precheck is a simple visual inspection of the battery and battery connections. Figure 10-1 shows some of the conditions that a visual inspection can reveal. Look for obvious damage such as a cracked *case* or *cover*. Also look for loose or broken battery connections or posts. Inspect the battery *cables* for wear or corrosion. *Corrosion* is a green deposit that can form from *battery electrolyte* (acid solution) that spills or splashes from the battery. Corrosion may build up on metal parts near the battery, usually on the *hold-down bracket* and *post* connections. When it forms on the post connections, it works its way between the battery post and the *cable* connection. This will eventually increase the resistance at the post to the point that the battery will not be able to supply enough power to crank the engine.

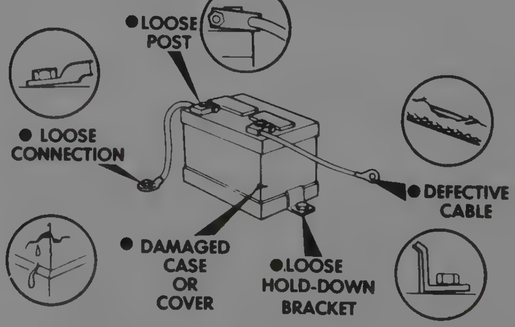


Figure 10-1. Conditions to look for when visually inspecting the battery. (Courtesy of American Motors Corporation)

Inspect the top of the battery for dirt or electrolyte. (Excessive electrolyte on the top of the battery may be the result of over-filling.) If the top of the battery is not clean, current can flow across the foreign material. This will cause the battery to discharge by itself. Check the battery hold-down bracket to be sure it is tight. A loose hold-down bracket could mean the battery has vibrated the *active material* (lead) off the plates.

If the battery has removable *vent caps*, remove the vent caps to inspect the electrolyte level. The electrolyte level should be above the top of the battery *plates*. If not, water, preferably distilled, must be added to the battery *cell* prior to any further testing.

BATTERY HYDROMETER TEST

After a visual inspection, the next precheck is to perform a **specific gravity test** to determine the battery's *state of charge*. This test can be made only on batteries with removable *vent caps* or on certain maintenance-free batteries with a pry-off strip. As the battery is discharged, the *sulfuric acid* in the electrolyte combines with the active material on the plates. As a result, the remaining electrolyte is nearly pure water. There is a direct relationship between the state of charge of the battery and the water content of the electrolyte. The specific gravity test determines the water content of the electrolyte, which in turn is a measure of the battery's state of charge.

Using the Hydrometer

The tool used to measure specific gravity is a **hydrometer** (Figures 10-2 and 10-3). The hydrometer is a *glass barrel* with a *squeeze bulb* at the top. The end of the hydrometer is inserted into the cell through the *vent cap hole*.

CAUTION: When inserting the tip of the hydrometer into the cell, take care to avoid damaging the battery separators. Broken separators could result in premature battery failure.

The squeeze bulb is compressed and released to draw electrolyte out of the cell and into the glass barrel, about halfway up. A *float* in the glass barrel floats in the drawn electrolyte. The float must not touch the bottom of the glass barrel. If the electrolyte has a high concentration of sulfuric acid, the float will not sink very far below the electrolyte level. If the electrolyte is mostly water (low concentration of sulfuric acid), the float will sink.

NOTE: *The electrolyte level of the battery must be at normal height prior to a specific gravity test. If water must be added, it should be mixed thoroughly with the electrolyte by charging the battery before the test is performed.*

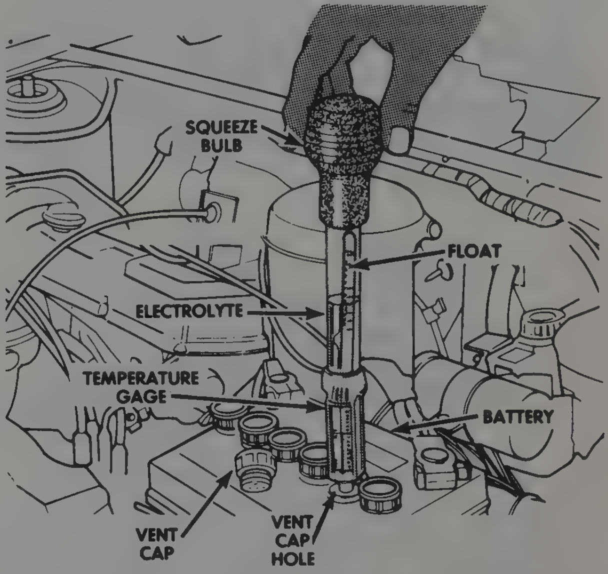


Figure 10-2. Using the hydrometer to check the condition of the battery. (Courtesy of Chrysler Corporation)

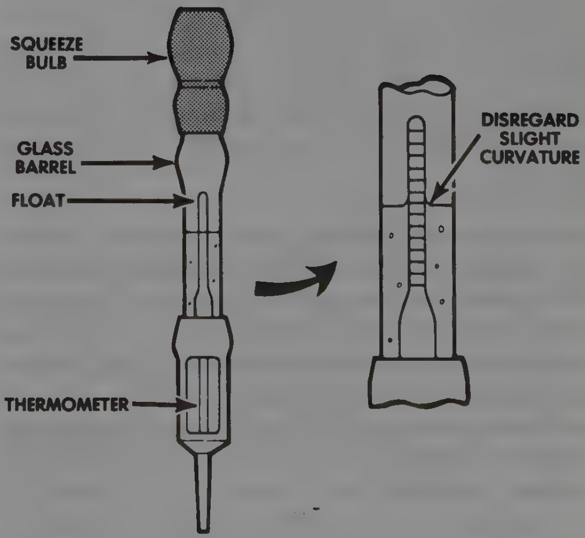


Figure 10-3. Reading the battery specific gravity from a hydrometer. (Courtesy of American Motors Corporation)

Reading the Hydrometer

Numbered graduations on the float scale allow the technician to read the hydrometer by sighting across the level of the electrolyte in the glass barrel at the float. The hydrometer must be held vertically and at eye level. The curvature of the electrolyte against the float where the surface rises must be disregarded (Figure 10-3).

The specific gravity scale uses 1.000 for pure water. Numbers greater than 1.000 indicate a higher specific gravity or higher concentration of sulfuric acid. Most hydrometers use a scale graduated to read from 1.120 to 1.320 in graduations of .005 specific gravity. Readings on a hydrometer would be as follows for various states of charge:

STATE OF CHARGE	SPECIFIC GRAVITY
Fully Charged	1.265
75% Charged	1.225
50% Charged	1.190
25% Charged	1.155
Discharged	1.120

Temperature Correction

Hydrometer floats are generally calibrated to indicate correctly only at one fixed temperature, 80° F. The temperature correction factor amounts to approximately .004 specific gravity (referred to as 4 points of gravity). For each 10° F above 80° F, add 4 points. For each 10° F below 80° F, subtract 4 points. Always correct the readings for temperature variation and test the specific gravity of the electrolyte in each battery cell.

Temperature Correction Example. If a battery tested at 20° F has a specific gravity of 1.280, its actual specific gravity is found as follows: (*NOTE: Electrolyte temperature is obtained from the thermometer (Figure 10-3) in the hydrometer.)*

- Number of degrees below 80° F equals 60° (80° − 20°).
- 60° divided by 10° (each 10° difference) equals 6.
- 6 x .004 (temperature correction factor) equals .024.
- Temperature is below 80°, so temperature correction is subtracted. Temperature-corrected specific gravity equals 1.280 minus .024, which equals 1.256.
- A fully charged battery should have a specific gravity of 1.250 to 1.265. Therefore, this battery is fully charged.

NOTE: Some hydrometers are self-correcting, so no temperature correction is necessary. Check the instructions for the particular hydrometer.

If the specific gravity of all cells is above 1.235, but the variation between cells is more than 50 points (.050), the battery is unserviceable. It should be replaced. If the specific gravity of one or more cells is less than 1.235, recharge the battery at approximately 5 amperes until three consecutive hourly readings are constant. At the end of the charge period, if the cell variation is more than 50 points (.050), replace the battery.

WARNING: Eye protection must always be worn when servicing batteries. If electrolyte is splashed in the eyes, the eye should be immediately flushed with cool, clean water for about five minutes. A doctor should also be contacted immediately. Electrolyte on the skin or clothing can be neutralized with a solution of baking soda and water. A container of baking soda should always be handy when batteries are serviced.

BATTERY LOAD TEST

The next precheck for a battery that has passed a specific gravity is a **load test**, also called a *performance test*. In this test, the battery is connected to a load. The load discharges the battery at a high rate to determine if it has enough *capacity* — the ability to deliver current. There are many types of load testers available. Many load testers have a series of programmable tests which alternately charge and discharge the battery while monitoring the battery's voltage. **CAUTION: Always follow the specific procedure recommended in the instructions provided with the load tester being used.**

A typical battery load tester is shown in Figure 10-4. It has a *voltmeter* and an *ammeter*, each with a *selector switch* for different measuring scales. A *load control* knob allows the technician to place the battery under a load.

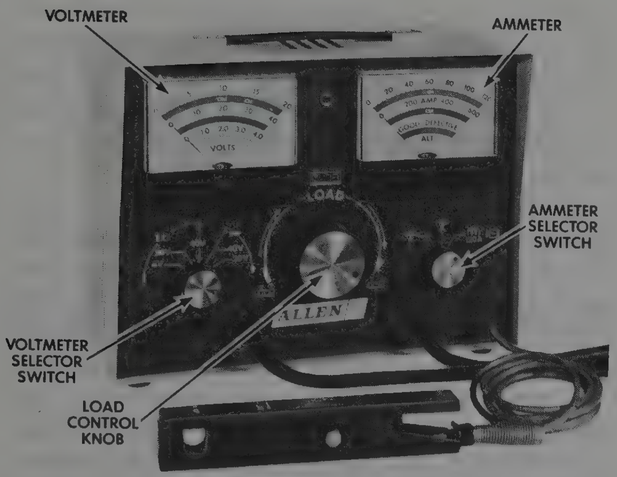


Figure 10-4. Typical battery load tester used to check battery performance.

The battery is connected to the battery load tester and the test made according to the procedure supplied with the tester. Typical connections are shown in Figure 10-5. A *black negative load lead* is connected to the battery negative (−) post, and a *red positive load lead* connected to the battery positive (+) post. An *inductive ammeter lead* is connected to the red positive load lead.

After connections are made and the load control knob is in the OFF position, the voltmeter will show battery voltage. The ammeter will be at zero because there is no current flowing. Following the tester manufacturer's instructions, the technician turns the load control knob to place the battery under a load. The amount of load is observed by noting the ampere reading on the ammeter. At the same time, the technician observes the voltmeter to see how far the battery voltage drops. The load must be applied to the battery for a specified short time, usually 15 seconds. **CAUTION: Leaving the load on too long can damage the battery.**

A good battery will maintain a voltage of 10 volts or more for at least 15 seconds at the specified amperage load. A fair battery will read 9.6 to 9.9 volts. Batteries that test in this range can be used to perform starting system tests and ignition tests. A load voltage of less than 9.6 volts means that the battery is not serviceable in its present condition. *In this case, the battery should be completely tested to determine if it is defective and needs replacing, or if it is merely in need of a recharge.*

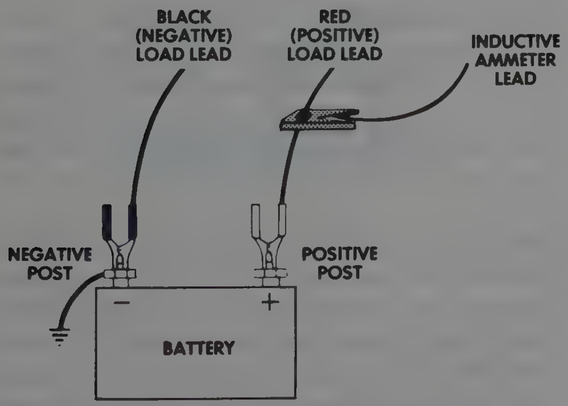


Figure 10-5. Typical connections for attaching a battery load tester. (Courtesy of Sun Electric Corporation)

STARTER MOTOR AMPERAGE DRAW TEST

A starter motor problem can prevent an engine from cranking fast enough to start. The starter motor may require so much current that the battery cannot handle the demand and at the same time supply the ignition system.

NOTE: *Before conducting any checks or tests, check the starter motor visually to be sure that it is solidly mounted to the engine.*

If the problem is a starting system that will not crank the engine at all, and if all the previous checks fail to uncover the problem, the starter motor must be removed for further testing. If the problem is a starting system that cranks the engine too slowly, the starter motor may be tested on the vehicle.

The condition of the starter motor can be determined by the starter motor amperage draw test. This precheck shows how much current the starter motor uses, or draws. The amount of current a starter motor should draw is listed in the service specifications for that vehicle. In general, starter motors for small four-cylinder and six-cylinder engines draw about 200 amps. The starter motors on large eight-cylinder engines work harder and draw as much as 400 amps.

Several manufacturers of electrical testing equipment produce a **starter motor amperage**

draw tester (Figure 10-6). The tester incorporates an ammeter, a voltmeter, and a loading device called a *carbon pile*. In addition, it is usually combined with a battery load tester. *Instructions for hookup and testing procedures are supplied by the manufacturer and should be followed exactly*. With all starter motor amperage draw testers, the amount of current used (drawn) by the starter motor is indicated on the tester's ammeter. If the current drawn is within the range specified for the vehicle, the starter motor may be considered in satisfactory condition. If the current drawn is unusually high or low, a problem exists with the starter motor.

CAUTION: The starter motor should never be operated longer than 15 seconds at a time without pausing to allow it to cool for at least two minutes. Excessive cranking can cause overheating and serious damage to the starter motor.

The starter motor amperage draw test may be conducted with the starter motor in or out of the vehicle. If the starter motor is tested while it is in the vehicle, the engine should be at normal operating temperature. Any mechanical problem with the engine that makes it hard to crank will also affect the test.

An usually high amperage draw indicates either a mechanical or an electrical problem. Any condition that interferes with armature rotation, such as a bent shaft, worn bearings, or loose pole shoes, will cause the starter motor to draw excessive current. A shorted armature circuit or field circuit are typical electrical problems that cause a high amperage draw. Sometimes a starter motor draws excessive current but does not rotate its armature. This is often the result of a direct ground at the brushes or at the field connections.

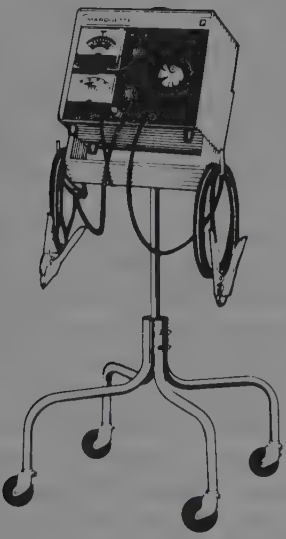


Figure 10-6. Battery starter tester used to check starter-motor amperage draw. (Courtesy of Marquette Products, Automotive Division of Applied Power, Inc.)

An unusually low amperage draw, accompanied by slow cranking speed, is an indication of high resistance within the starter motor. One of the field windings may be open, reducing the amount of current draw. This would also reduce the magnetic field and not allow enough torque for cranking. A starter motor that does not operate and does not draw any current has an open circuit. The open circuit may be at the windings armature, brushes, or commutator.

ALTERNATOR OUTPUT TEST

During cranking, the battery supplies power to the ignition system. When the engine starts, the *alternator* takes over. The alternator must provide enough power to meet all the vehicle's electrical demands and also supply the current needed by the ignition system.

Alternators are rated by the current they can deliver at a specified speed (RPM) and voltage. The **alternator output test** is a precheck used to measure the alternator's ability to produce its rated output. The vehicle manufacturer provides output specifications in its service literature. The output is specified at a certain engine RPM and voltage, because these affect the amount of current an alternator can deliver.

NOTE: Before starting an alternator output test, visually inspect the alternator for the following:

- *Loose alternator drive belt*: A loose belt can cause the alternator to run at a lower speed (RPM) and reduced output (Figure 10-7). Glazed, frayed, or worn spots on the belt also result in reduced output. The belt should be adjusted or replaced as necessary.
- *Wires and connections*: The wires connected to the alternator and regulator should be properly connected and in good condition. Wires are sometimes pinched under sheet metal edges or under screw heads. Worn insulation is common where a wire is loose and is rubbing against a rough metal surface or the threads of a screw.

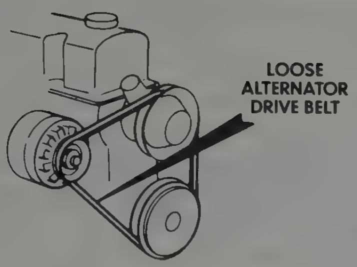


Figure 10-7. Illustration of where to check for a loose alternator drive belt. (Courtesy of American Motors Corporation)

- *External damage*: A cracked alternator *housing* may allow the *rear bearing* to move out of alignment and cause the *rotor* to rub on the *stator core*. A broken *mounting bracket* can cause the alternator to become misaligned with the drive belt. This will also cause noisy operation or low output.

Alternator output is often measured with a *generator-alternator-regulator tester* that incorporates a voltmeter, ammeter, and loading device (Figure 10-8). The manufacturer's instruction manual that is provided with the tester lists the tests that can be performed and describes the proper hookup for the tests. Usually the tester is connected to the charging circuit as shown in Figure 10-9. *NOTE: Consult the manual provided with the tester for the proper connections and test procedure.*

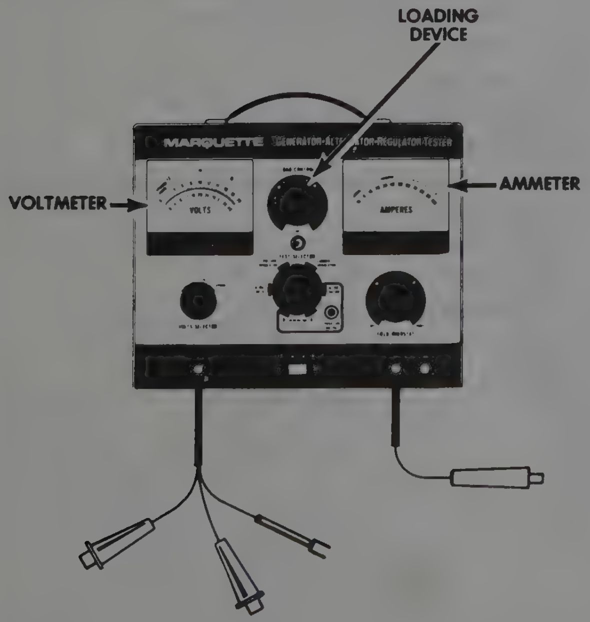


Figure 10-8. Tester used to measure alternator output. (Courtesy of Marquette Products, Automotive Division of Applied Power, Inc.)

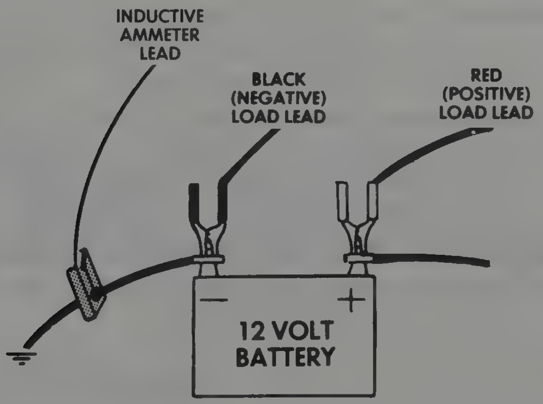


Figure 10-9. Typical connections for an alternator output test. (Courtesy of Sun Electric Corporation)

Different connections are required for different types of wiring systems (connections). The alternator output test involves setting the engine to a specified RPM measured with a tachometer. Then a carbon pile (loading device) on the tester is used to draw current from the alternator. The load is adjusted to a specified voltage on a voltmeter, and the current output is read on an ammeter.

An output of 2 to 8 amps below the specified rating usually indicates an open diode in the rectifier circuit. It could also indicate a slipping alternator drive belt. The belt should be rechecked. An output of 10 to 15 amps less than the specified rating usually indicates a shorted diode. An alternator with a shorted diode often has a noticeable whine at idle. An output considerably lower than specifications may indicate a shorted rectifier circuit or other internal, electrical problems. Any test indicating an alternator malfunction should be followed by a circuit resistance test to determine whether the circuit is faulty or if the alternator should be removed from the vehicle for servicing. An alternator that delivers the correct amount of current to pass the output test may be considered in satisfactory condition.

KEY TERMS

Alternator output test: A test that measures the alternator's ability to produce its rated output.

Hydrometer: A glass barrel with a float and a squeeze bulb at the top used to measure the specific gravity of battery electrolyte.

Load test: A test of battery capacity performed by connecting the battery to an electrical load and observing its voltage.

Specific gravity test: A test to determine the state of charge of a battery by using a hydrometer to measure the specific gravity of the electrolyte.

Starter Motor Amperage Draw Test: A test to determine how much current the starter motor is using, or drawing.

SELF-CHECK

1. List the charging and starting system prechecks that should be made prior to working on the ignition system.
2. Why is battery condition important?
3. What should the mechanic look for when visually inspecting the battery?
4. Why should eye protection be worn when servicing the battery?
5. What does the specific gravity tell about a battery?
6. How does a hydrometer measure specific gravity?
7. Why do some hydrometers have a thermometer?
8. Explain how to properly measure specific gravity of battery electrolyte.
9. What does a load test tell about a battery?
10. Explain how to perform a battery load test.
11. List the visual checks that should be made on the starting system.
12. What does a starter amperage draw test tell about a starting system?
13. List the visual checks that should be made on the charging system.
14. Explain how to perform an alternator output test.
15. Why is an alternator output test important?

DISCUSSION TOPICS AND ACTIVITIES

1. Study the manual for the tune-up equipment in your shop. Are there prechecks for the charging and starting systems?
2. Test a selection of shop batteries. How would their condition affect the ignition system?

CERTIFICATION PRACTICE

1. The electrolyte in a discharged battery is mostly:
   A. Water
   B. Sulfuric acid
   C. Both A and B
   D. Neither A nor B
2. Starting system wiring and connections should be checked for:
   A. Frayed insulation
   B. Corrosion
   C. Both A and B
   D. Neither A nor B
3. An unusually high starter amperage draw may be caused by a:
   A. Bent armature shaft
   B. Shorted armature circuit
   C. Shorted field circuit
   D. All of the above
4. Before starting an alternator output test, check the condition of the:
   A. Alternator drive belt
   B. Battery
   C. Indicator lamp circuit
   D. Regulator
5. Alternator output is specified at a certain:
   A. Engine RPM
   B. Voltage
   C. Both A and B
   D. Neither A nor B

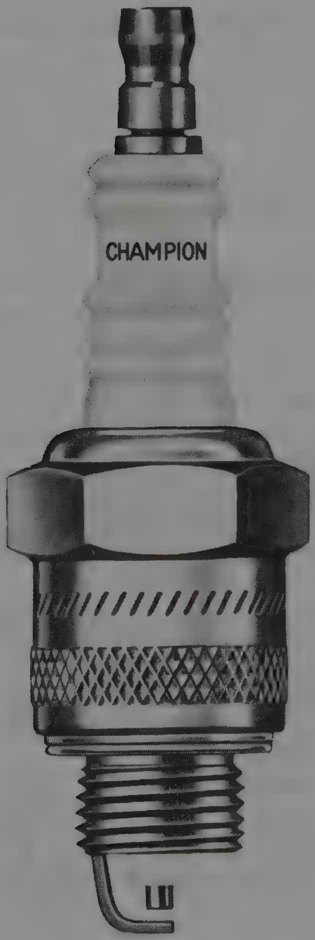
ANSWERS:

1:A, 2:D, 3:C, 4:A, 5:C

SECTION IV

Ignition System

Unit 11. Ignition Primary Circuit Operation
Unit 12. Ignition Secondary Circuit Operation
Unit 13. Ignition Advance Systems
Unit 14. Troubleshooting the Ignition System
Unit 15. Servicing the Ignition System



Unit 11 IGNITION PRIMARY CIRCUIT OPERATION

The purpose of the ignition system is to provide a precisely timed high-voltage spark to ignite the air-fuel mixture in each cylinder when it is ready for a power stroke. Ignition system troubleshooting and service are part of every tune-up. This unit describes the parts and operation of the ignition primary circuit. (The parts and operation of the ignition secondary circuit are covered in Unit 12.) The ignition primary circuit consists of a source of electrical energy, the ignition coil primary circuit, and the distributor breaker points or electronic primary circuit.

DEVELOPING JOB COMPETENCIES

When you finish reading and studying this unit, you should be able to:

- List the basic parts of the ignition system, and explain the purpose of each.
- Describe the parts and operation of the ignition coil.
- Describe the operation of a breaker point distributor primary circuit.
- Describe the parts and operation of an electronic distributor primary circuit.

REVIEW OF IGNITION FUNDAMENTALS

The ignition system (Figure 11-1) consists of the following basic parts:

1. *Source of electrical energy*: The source of electrical energy for the ignition system is the battery or alternator. When the engine is being started, the battery supplies the needed current. After the engine is running, current is supplied by the alternator or by the alternator and battery working together.

2. *Key switch*: The key switch or ignition switch allows the driver to start and stop ignition by opening and closing the circuit between the

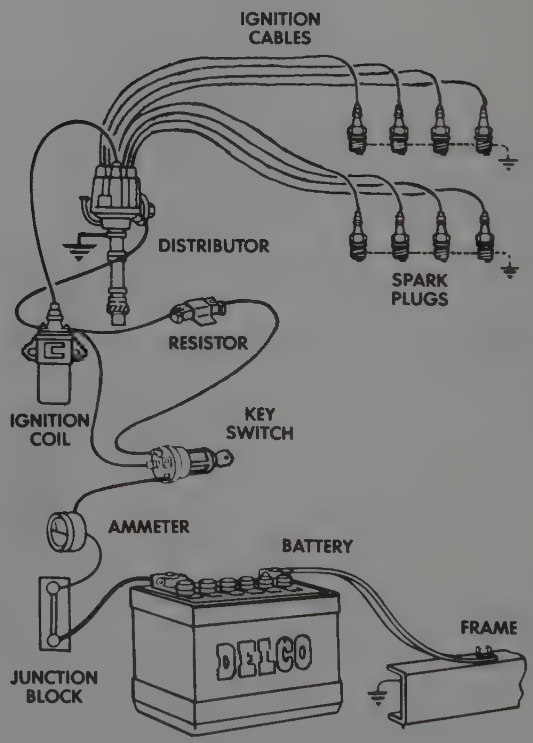


Figure 11-1. Pictorial wiring diagram for a basic ignition system. (Courtesy of Delco Remy, Division of General Motors Corporation)

electrical energy source and the other ignition components. The key switch usually has four positions: OFF, ACCESSORY, ON, and START.

3. *Ignition coil*: The voltage developed by the battery or alternator is not high enough to ignite the air-fuel mixture in the engine's cylinders. The function of the ignition coil is to step up, or transform, the low voltage available from the battery or alternator to the 30,000 or more volts required for ignition.

4. *Distributor*: The distributor has three jobs: First, it opens and closes a low-voltage circuit between the source of electrical energy and the ignition coil so that the ignition coil is supplied with intermittent surges of current. These intermittent surges are used to induce high-voltage current inside the ignition coil. Second, the distributor times the surges with respect to engine requirements. This is accomplished with centrifugal and vacuum advance mechanisms. Third, the distributor directs the high voltage developed by the ignition coil through high-voltage spark plug wires or ignition cables to the spark plugs.

5. *Spark plugs*: A spark plug located in each of the engine's combustion chambers accepts the high-voltage current developed by the ignition coil and directed by the distributor. The spark plug has an air gap that the current is forced to jump. As the current jumps across the spark plug air gap, a spark is developed. The spark ignites the air-fuel mixture in the cylinder. The burning air-fuel mixture is used to develop power in the engine.

6. *Primary and secondary circuits*: The ignition system is made up of two separate circuits, the primary and the secondary circuit (Figure 11-2). The wires and parts that direct the low-voltage current from the battery are part of the primary circuit. The wires and parts that direct the high-voltage current are part of the secondary circuit.

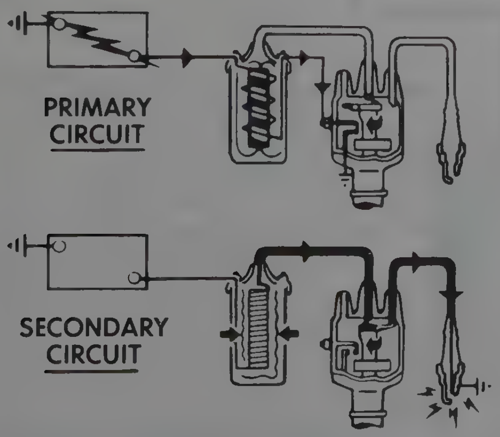


Figure 11-2. The ignition system is made up of a primary circuit and a secondary circuit. (Courtesy of Delco Remy, Division of General Motors Corporation)

IGNITION COIL

The **ignition coil** is an electrical device that transforms, or steps up, the low battery or alternator voltage to the high voltage necessary to "jump" the air gap at the spark plug in each of the engine cylinders.

Ignition Coil Construction

The ignition coil, shown in a cutaway view in Figure 11-3, contains three basic parts: a **primary winding** consisting of a few hundred turns of heavy wire, a **secondary winding** consisting of several thousand turns of fine wire, and a laminated *soft iron core* which serves to concentrate the magnetic field. The primary winding is wound around the outside of the secondary winding, and the laminated soft iron

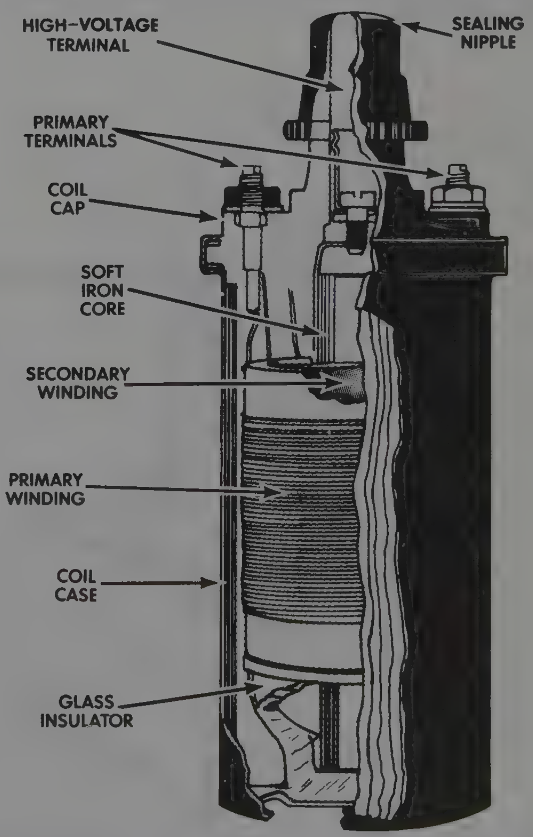


Figure 11-3. Cutaway view of an ignition coil. (Courtesy of Sun Electric Corporation)

core is placed in the center of the windings. This assembly is placed in the *coil case*. A *glass insulator* prevents the assembly from contacting the coil case. The remaining space is filled with oil and a *coil cap* is put into place. A *high-voltage terminal* at the center of the coil cap is used to connect the secondary high-voltage cable to the ignition coil. A *sealing nipple* prevents moisture from entering the terminal. Two *primary terminals* allow the coil's primary winding to be connected into the circuit.

Ignition Coil Operation

The high-voltage current required to ignite the air-fuel mixture in the engine's combustion chambers is developed by the process of *induction* (described in Unit 3). Induction involves the transfer of energy from one object to another without the objects physically touching.

The use of induction in an ignition system is illustrated in Figures 11-4 and 11-5. In Figure 11-4, current flows from the *battery* to a *starter relay* and then to the *key switch*. If the key switch is in the ON position, current can flow through the *ignition primary wire* and into the *primary winding* of the *ignition coil*. It then flows out of the primary winding through the *distributor primary wire* and through the closed *breaker points* to *ground*. A complete circuit and a magnetic field exists around the primary winding. During the time that the breaker points remain closed, the flow of current is increasing and energy is being stored in the ignition coil.

For the principle of induction to operate, the magnetic field around the primary winding must be collapsed. This is accomplished by the *breaker cam* and breaker points, both of which are located in the distributor. (Breaker points are discussed in more detail later in this unit, under the heading of "Breaker Point Distributor Primary Circuit.")

When the *breaker points* open (Figure 11-5) current ceases to flow through the primary winding, and its magnetic field collapses. (When the breaker points first begin to open, the current is directed to the *condensor*, which is discussed in detail later in this unit, under the heading of "Condensor.") When this happens, current is induced into the *secondary winding* of the ignition coil. This high-voltage current is directed through spark plug wire to the spark plug.

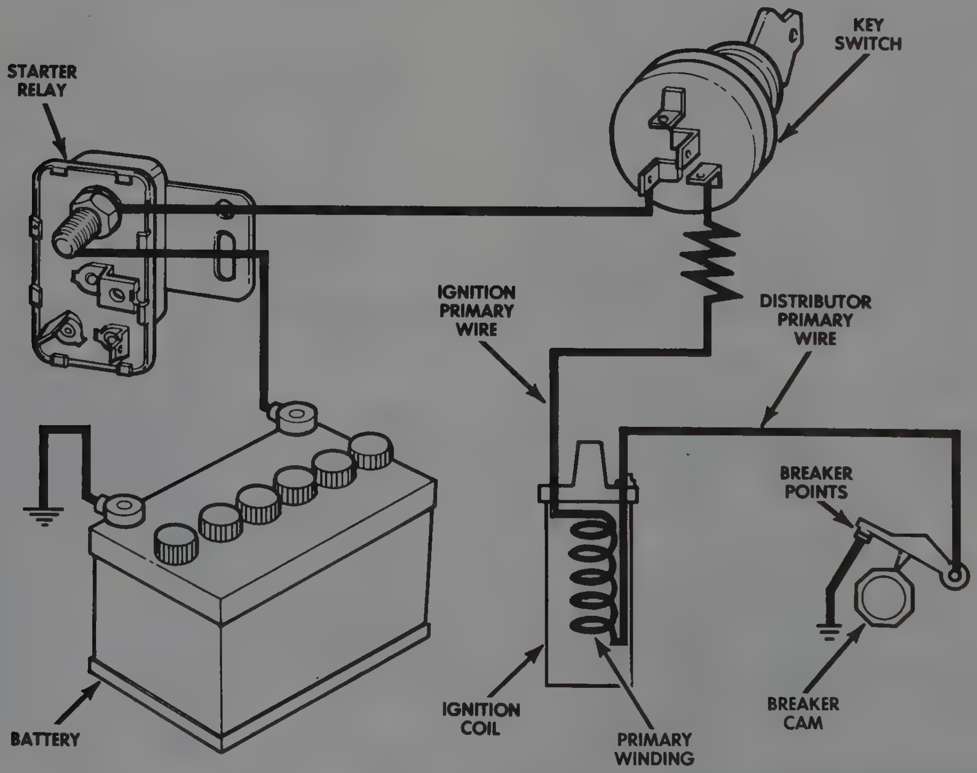


Figure 11-4. With the breaker points closed, current flows in the primary winding to build a magnetic field. (Courtesy of Chrysler Corporation)

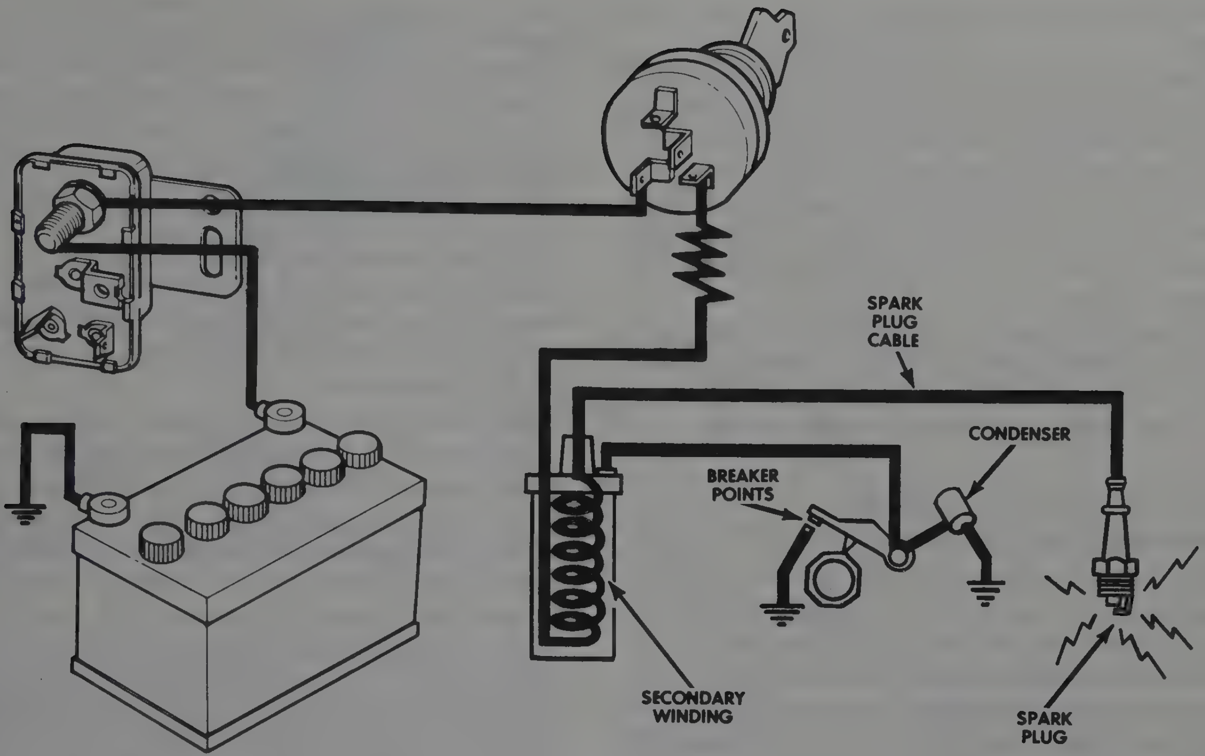

SPARK
PLUG
CABLE
CONDENSER
BREAKER
POINTS
SECONDARY
WINDING
SPARK
PLUG

Figure 11-5. When the breaker points open and the magnetic field around the primary winding collapses, a high voltage is induced in the secondary winding. (Courtesy of Chrysler Corporation)

Voltage continues to build up in the secondary circuit until there is enough voltage, or pressure, to "jump" the air gap at the spark plug and ignite the air-fuel mixture. Only enough voltage is produced to jump the air gap. This voltage can vary from 7,000 to 30,000 volts or more, depending upon the power demands on the engine and the condition of the electrical system.

DISTRIBUTOR

The distributor (Figure 11-6) has three important functions: *(NOTE: The distributor in Figure 11-6 is a breaker point distributor. Ignition systems that use electronic distributors are covered later in this unit.)*

First, it opens and closes the primary circuit between the source of electrical energy and the ignition coil so that the primary winding is supplied with intermittent surges of current. Each surge of current builds up a magnetic field in the coil. The distributor then opens its circuit so that the magnetic field will collapse

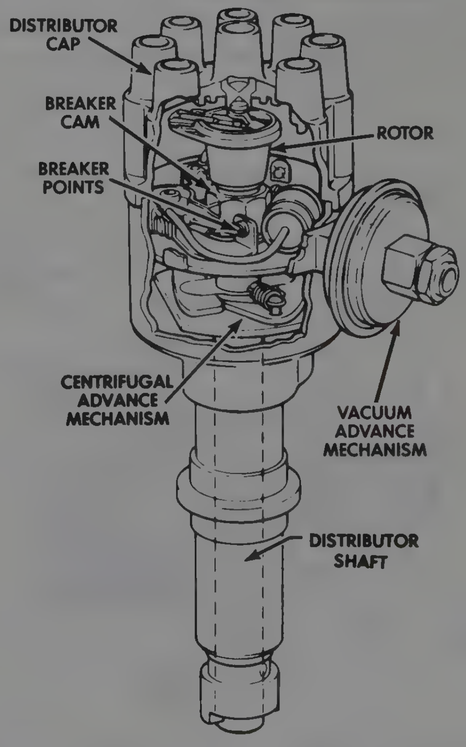

DISTRIBUTOR
CAP
BREAKER
CAM
BREAKER
POINTS
ROTOR
CENTRIFUGAL
ADVANCE
MECHANISM
VACUUM
ADVANCE
MECHANISM
DISTRIBUTOR
SHAFT

Figure 11-6. Main parts of a distributor that uses breaker points. (Courtesy of Delco Remy, Division of General Motors Corporation)

and cause the coil to produce a high-voltage surge.

Second, the distributor has to time these high-voltage surges with regard to the engine requirement. This is accomplished by the *centrifugal advance* and *vacuum advance mechanisms*. Third, the distributor directs the high-voltage surge through the *rotor*, *distributor cap*, and spark plug wire to the spark plug which is ready to fire.

Depending upon the type of distributor used in the ignition system, the distributor primary circuit may be a *breaker point primary circuit* or an *electronic distributor primary circuit*.

Breaker Point Distributor Primary Circuit

The breaker point distributor primary circuit is opened and closed by a mechanical switch called **breaker points** or *contact points* and the *breaker cam* (Figure 11-6). The breaker cam is rotated by the distributor's *shaft*. The shaft is driven by gearing within the engine, usually by the engine camshaft. The distributor shaft and breaker cam are rotated at half the engine speed, and the breaker cam has the same number of *lobes* (on most applications) as there are cylinders in the engine.

As each *breaker cam lobe* (Figure 11-7) passes under the *rubbing block* of the *breaker arm*, the breaker points (*stationary breaker point* and *movable breaker point*) are opened so that a high-voltage surge is produced. During every breaker cam revolution, one spark is produced for each engine cylinder. Since each cylinder fires during every other revolution in a four-cycle engine, each cylinder will fire once for every two crankshaft revolutions or once for every single breaker cam revolution.

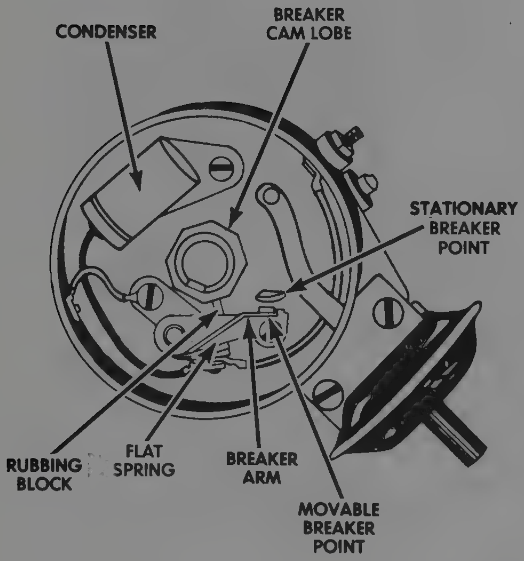


Figure 11-7. Details of the breaker point assembly in the distributor. (Courtesy of Sun Electric Corporation)

The breaker points are made of highly wear-resistant tungsten to help reduce metal transfer from the movable breaker point to the stationary point or vice versa.

Condenser. An ignition system with breaker points requires an electrical component called a **condenser** (or *capacitor*) for proper operation. A condenser is an electrical storage device which can store a certain amount of electricity. Condensers come in different shapes and sizes. The amount of electricity they can store is measured in microfarads (μF). The condenser has two important jobs: First, it protects the breaker points from burning. Second, it assists in the collapse of the magnetic field in the ignition coil.

The condenser is made up of two separate windings of *foil* (Figure 11-8) that are separated from each other by *insulation paper*. One foil winding is connected to the *lead wire* or *pigtail* of the condenser, and the other foil winding is connected to the *case* or *condenser can*. The foil and the insulation paper are wound into a tight roll, and the roll is installed in the case.

When the breaker points first start to open, the current flowing through them tends to form an arc. The arc tends to burn the breaker points and thus reduce their life. When the breaker points start to open, the current continues to flow, but not across the breaker points. Instead, it surges into the condenser and fills it up (charges it). By the time the condenser is charged all the way, the breaker points have opened so far that the primary voltage can no longer push a spark across them.

Once the condenser is charged, no more current will flow; thus, the current flow through the primary winding is stopped immediately. Without a condenser, the current would not stop rapidly, but would taper off as the breaker points opened and the spark (arc) across them diminished. With a rapid halt of current flow, the magnetic field collapses rapidly too, so that the voltage which is built up in the coil secondary winding is much greater.

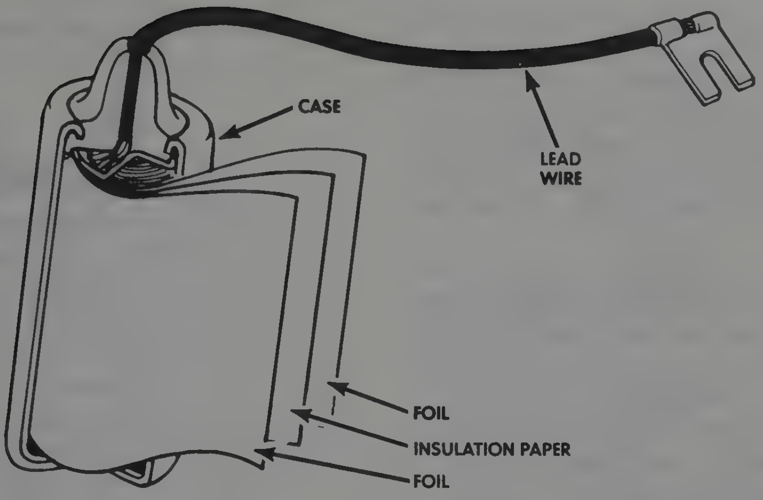


Figure 11-8. A typical condenser is made from layers of foil separated by insulation paper. (Courtesy of Chevrolet Motor Division, General Motors Corporation)

Electronic Distributor Primary Circuit

Mechanical breaker points have a limited service life. Eventually the contact surfaces burn away and the rubbing block wears down. The wear on the rubbing block changes timing, and the burned breaker points resist current flow. The result is that engine performance suffers. These problems may be overcome by using solid state electronic components, called *transistors* to replace the mechanical breaker points.

An **electronic ignition distributor** may be called a *breakerless distributor, transistorized distributor, high-energy distributor,* or *electronic distributor*. These distributors allow a higher primary current to be used without the risk of burning the breaker points. A higher secondary voltage is induced, resulting in cleaner, longer-lasting spark plugs, less engine misfire, and a lower level of undesirable emissions. Transistors do not wear out, and they can handle a much higher voltage than breaker points. They also operate more efficiently and much more quickly than breaker points.

Transistor Operation. As mentioned in Unit 9, transistors are electrical devices which act as electrical switches. They can be turned on or off to control a circuit and to fulfill the same function as a set of breaker points that turn the circuit on when they are closed and off when they are open. *For simplicity, it is best to consider the transistor as a chemical device with electrical characteristics*. In Figure 11-9, there are two pieces of "P" semiconductor material and one piece of "N" semiconductor material.

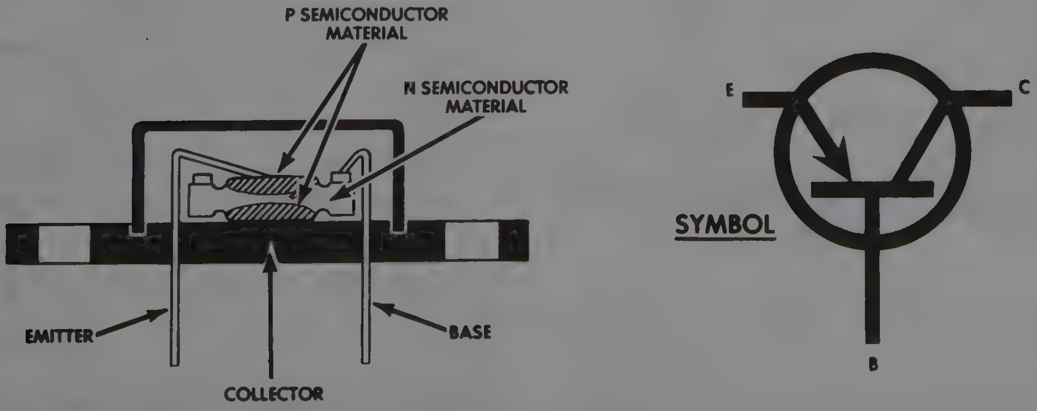


Figure 11-9. Cross section of a transistor and its symbol. (Courtesy of Delco Remy, Division of General Motors Corporation)

(The "P" and "N" designations are arbitrary for this discussion.) The way in which these materials will react when subjected to current can be predicted. Figure 11-9 shows the transistor symbol used in wiring diagrams. *NOTE: For the sake of simplicity, the arrow in the transistor symbol always points in the direction of current flow.*

The transistor has characteristics that make it very useful in controlling current flow (Figure 11-10). The main current in a circuit cannot pass through the emitter (E) to the collector (C) unless a small amount of current is allowed to pass through the emitter-base circuit. Thus, a small amount of current is used to control (by trigger or switch) a large amount of current.

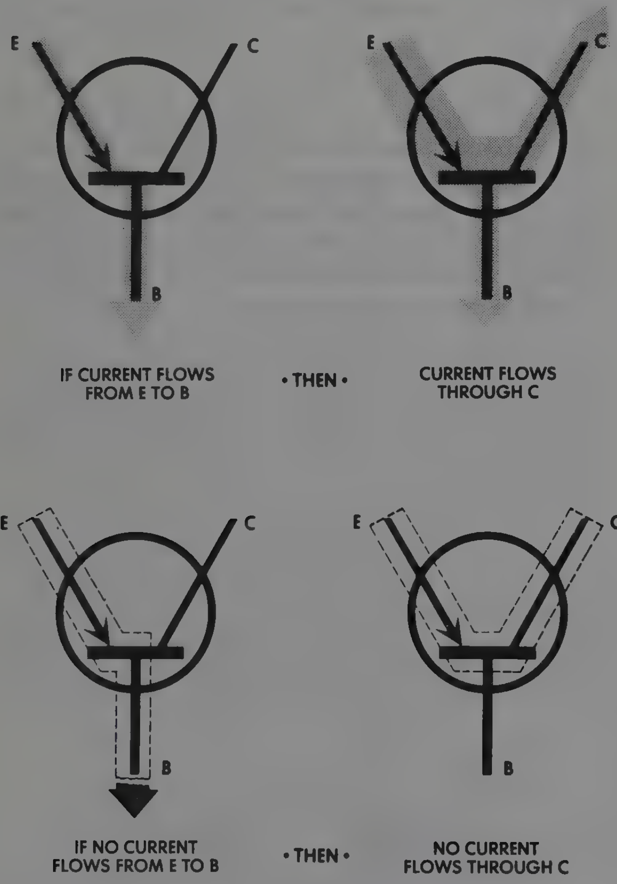

E
C
B
IF CURRENT FLOWS FROM E TO B
• THEN •
CURRENT FLOWS THROUGH C
IF NO CURRENT FLOWS FROM E TO B
• THEN •
NO CURRENT FLOWS THROUGH C

Figure 11-10. Illustration of how a transistor controls current flow. (Courtesy of Delco Remy, Division of General Motors Corporation)

It is possible to use a *mechanical switch* to control a transistor (Figure 11-11). If the mechanical switch were closed, a very small amount of current would flow across the emitter-base circuit, and this would allow full current to flow from the emitter (E) across the base (B) to the collector (C) in the same way shown in Figure 11-10.

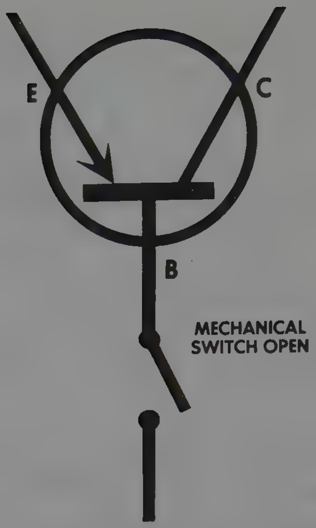


Figure 11-11. A transistor can be controlled by a mechanical switch. (Courtesy of Delco Remy, Division of General Motors Corporation)

It is also possible to control a transistor circuit electrically. An example of this is shown in Figure 11-12. Only when the emitter-base circuit has the correct voltage polarity applied to it will it carry current and thereby permit current to flow in the emitter-collector circuit. When the polarity of the voltage is reversed, the emitter-base circuit is turned off, and no current can flow in the emitter-collector circuit. For a transistor to work as a mechanical switch, a circuit must be designed in which the transistor is controlled by different voltage polarity. In a transistorized ignition system, a transistor housed in a control unit is triggered by a signal

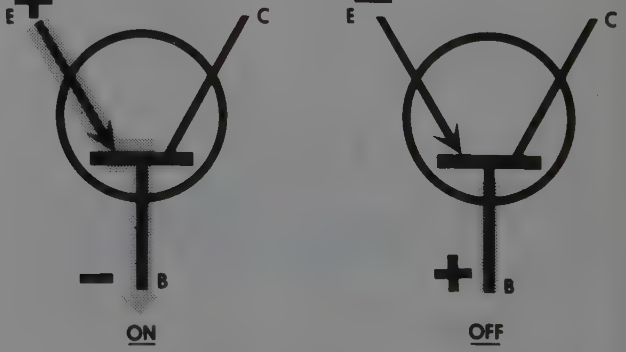


Figure 11-12. Transistors can be controlled electrically. (Courtesy of Delco Remy, Division of General Motors Corporation)

from the distributor. The transistor is used to turn the coil primary on and off and induce a high voltage in the secondary circuit.

Electronic Ignition Distributor Parts. Many components of the electronic ignition distributor (Figure 11-13) are the same as those for a breaker point distributor. (Refer to Figures 11-6 and 11-13 to compare their construction and components.) Both ignition systems use the same type of ignition coil and spark plugs. The main difference between the two distributors is that the *breaker points* in the breaker point distributor is replaced with a *pickup unit* in the electronic distributor, and the *cam* is replaced with a *reluctor* (Figure 11-14).

The pickup unit consists of a permanent magnet and a coil that is wound around a pole piece. The pole piece is an extension of the mounting bracket and is attached to the permanent magnet. Because of this arrangement, the pickup unit resembles a horseshoe-type magnet, with the reluctor end of the pole piece acting as one of the poles.

The reluctor is a gear-like component that is attached to the distributor shaft in the same position as the cam in a breaker point distributor. The reluctor is not a magnet, but it does provide a better magnetic path than air. In other words, it is capable of reducing *reluctance* (resistance to the flow of magnetic lines of force).

Electronic Distributor Operation. The reluctor and the pickup unit in an electronic ignition distributor do electrically what the cam and rubbing block do mechanically in a breaker point distributor. Although the electronic distributor components replace the cam and breaker points, they operate quite differently. In a breaker point distributor, the current flowing through the primary winding of the ignition coil is interrupted when the breaker points are opened by the rotating cam. The collapsing magnetic field in the primary winding induces enough voltage in the secondary winding to fire the spark plugs. In the electronic ignition distributor, a permanent magnet in the pickup unit provides a magnetic field from the pole piece to the permanent magnet. This permanent magnetic field passes through the pickup unit coil that is wound around the pole piece. The magnetic field is relatively weak, because

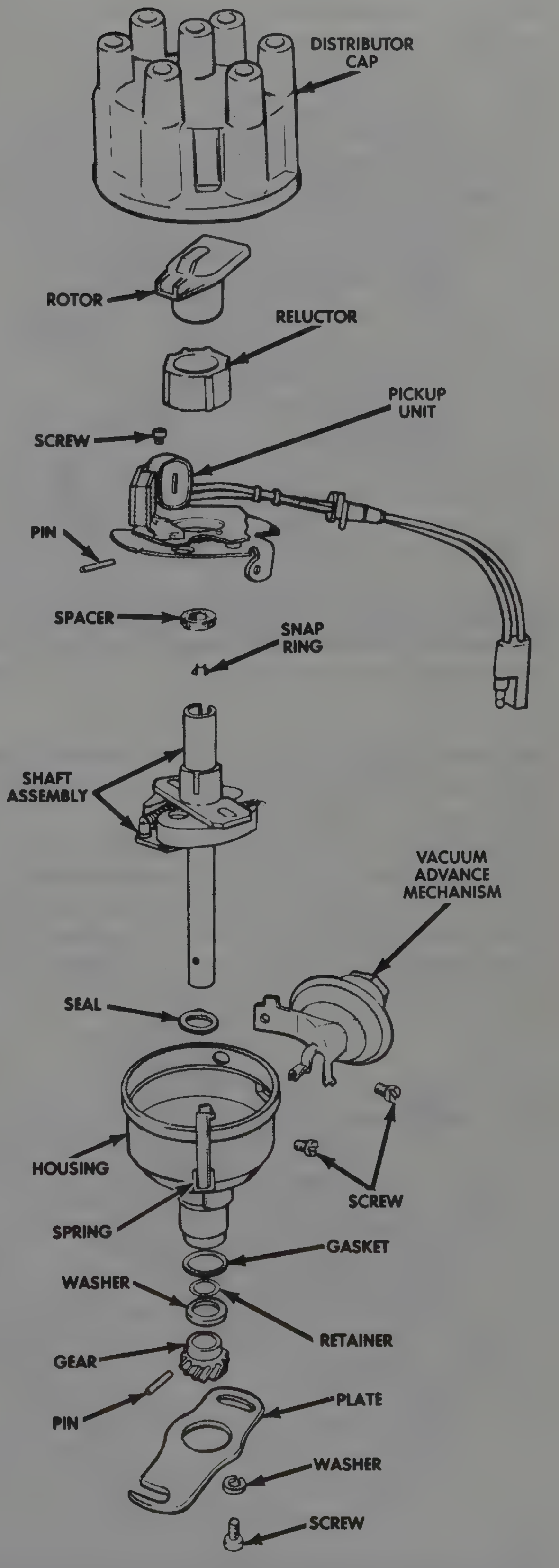


Figure 11-13. Exploded view of an electronic ignition distributor. (Courtesy of Chrysler Corporation)

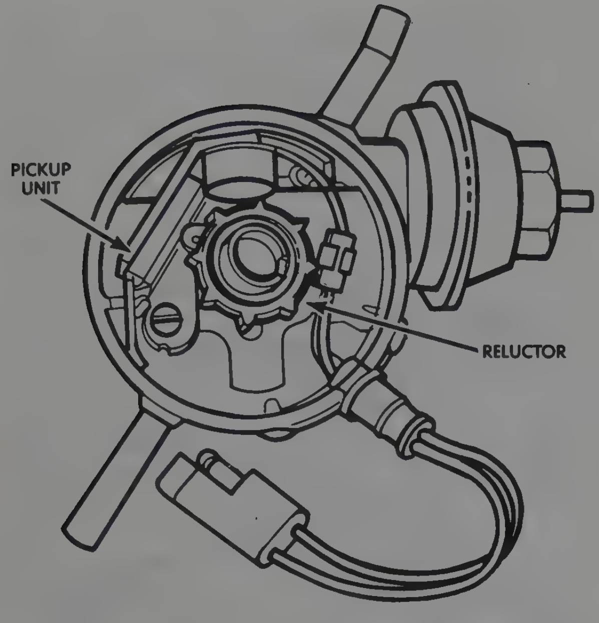

PICKUP UNIT
RELUCTOR

Figure 11-14. The two main parts of an electronic distributor that differ from those of a breaker point distributor. (Courtesy of Chrysler Corporation)

the wide air gap (Figure 11-15) between the *pole piece* and the *permanent magnet* does not provide a good magnetic path.

As a *tooth* of the reluctor approaches the *pole piece* (Figure 11-16), it provides a better path than the wide air gap provides, and the strength of the magnetic field in the pickup unit is increased. Increasing the magnetic field strength at the pickup unit coil induces a positive (+) voltage at one terminal of the coil. This voltage is induced as a result of the changing (increasing) magnetic field strength. It is not caused by the physical movement of the magnetic field or the pickup unit coil. The positive (+) voltage continues to build until the reluctor tooth is exactly opposite the pole piece.

As soon as the reluctor tooth passes the pole piece (Figure 11-17), the air gap widens and the magnetic field weakens once again. The weakened magnetic field through the coil in-

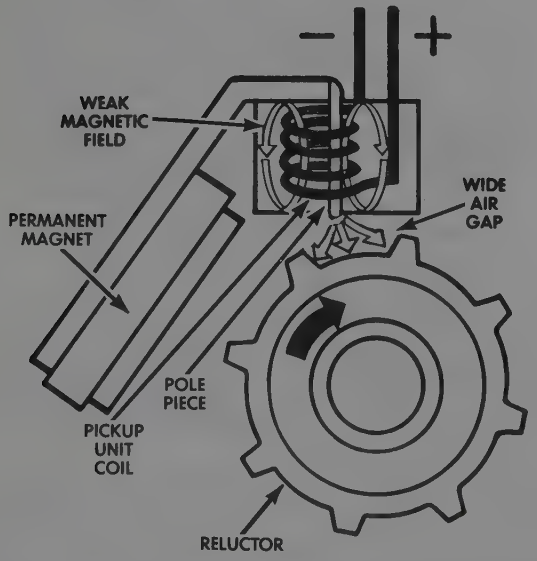

−
+
WEAK MAGNETIC FIELD
WIDE AIR GAP
PERMANENT MAGNET
POLE PIECE
PICKUP UNIT COIL
RELUCTOR

Figure 11-15. A wide air gap offers resistance to the flow of magnetic lines of force. (Courtesy of Chrysler Corporation)

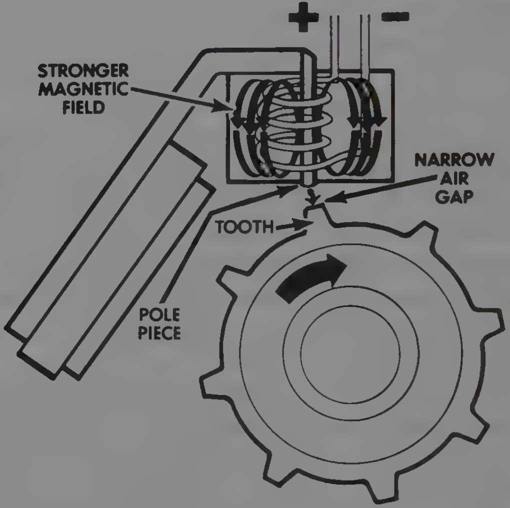

+
−
STRONGER MAGNETIC FIELD
NARROW AIR GAP
TOOTH
POLE PIECE

Figure 11-16. Increasing the strength of the magnetic field induces a positive (+) voltage in the pickup unit coil. (Courtesy of Chrysler Corporation)

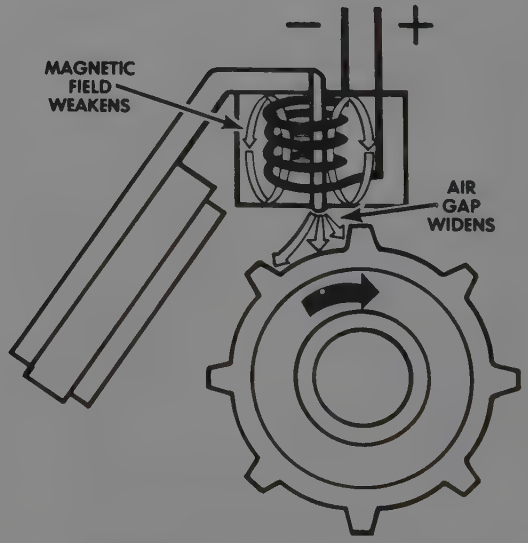

−
+
MAGNETIC FIELD WEAKENS
AIR GAP WIDENS

Figure 11-17. A weakened magnetic field induces a negative (−) voltage in the pickup unit coil. (Courtesy of Chrysler Corporation)

duces a negative (−) voltage at the same terminal of the pickup unit coil winding. Again, the voltage is induced by the change (reduction) in magnetic field strength. No voltage is induced in the pickup unit coil unless the reluctor is moving. The rapid increase and decrease of the magnetic field as the rotating reluctor teeth approach and pass the pole piece induces the positive (+) and then the negative (−) voltage.

The induced voltage is a very small electrical signal that is fed into the electronic control unit (Figure 11-18). The function of the signal voltage induced in the pickup unit does not serve the same function as that of the contacts (breaker points) in a breaker point distributor. (The breaker points open and interrupt the primary current in the ignition coil.) The pickup voltage is a precisely timed signal which triggers the electronic circuitry in the electronic control unit. The electronic circuitry in turn controls the interruption of the current flowing through the primary winding of the ignition coil.

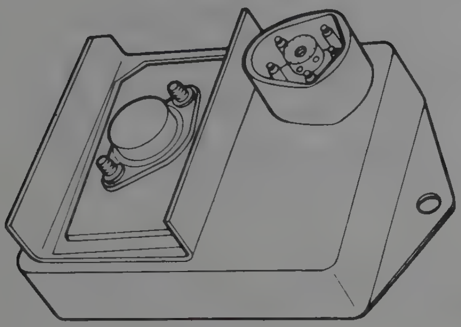


Figure 11-18. Typical electronic control unit used to control the interruption of current flow through the primary winding of the ignition coil. (Courtesy of Chrysler Corporation)

Battery current flows through the *primary winding* of the *ignition coil* and then through the *electronic control unit* to ground as shown in Figure 11-19. This maintains current flow in the primary winding in the same way the closed contacts do in a breaker point distributor. The electronic control unit remains on (activated), and current flows through the primary coil windings as long as a negative (−) voltage from the pickup unit is not applied to it.

When the *reluctor* passes the pole piece of the pickup unit, the voltage turns negative (−), and it turns off (deactivates) the *electronic*

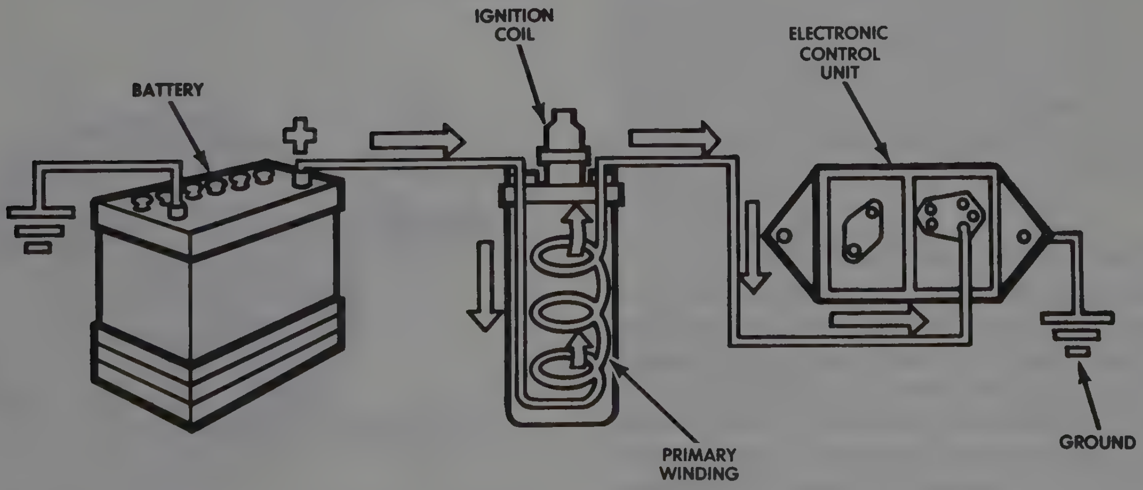


Figure 11-19. Current flow through the electronic control unit allows the primary winding to build up a magnetic field. (Courtesy of Chrysler Corporation)

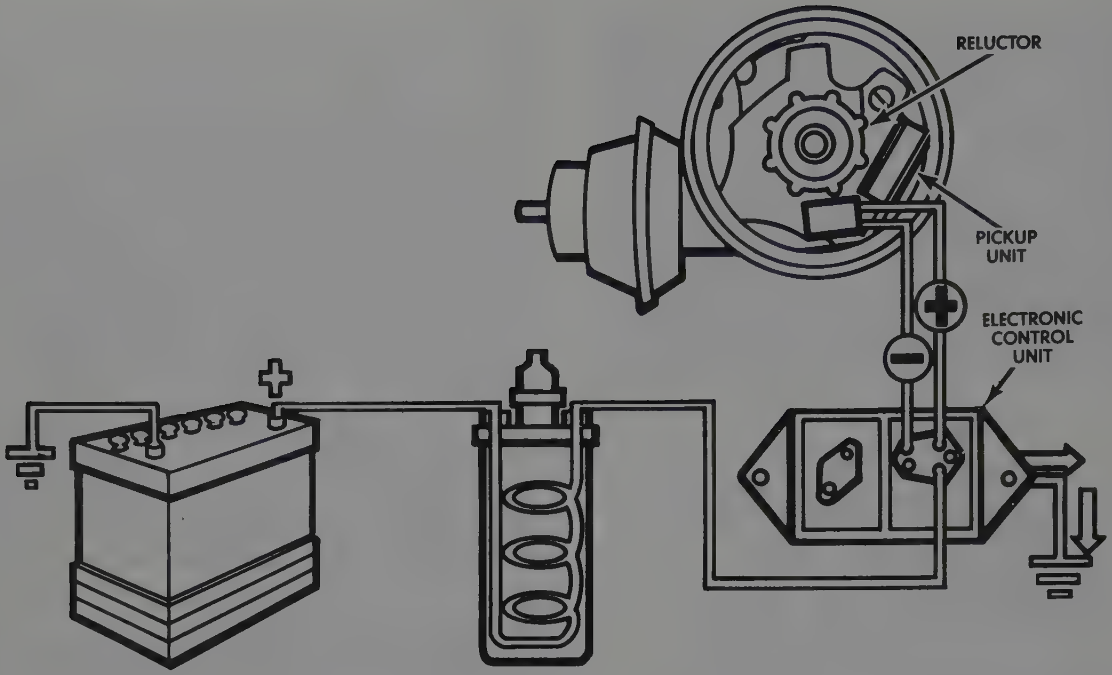


Figure 11-20. A negative (–) voltage from the pickup unit interrupts the primary winding current, and a current is induced in the secondary winding. (Courtesy of Chrysler Corporation)

control unit circuitry (Figure 11-20). At this point, current cannot flow through the electronic control unit to ground; therefore, the current through the primary winding is interrupted. This interruption of current flow in the primary winding induces enough voltage in the secondary windings of the ignition coil to fire the spark plug.

Internal Electronic Control Unit

Smaller electronic components have made it possible to design an electronic control unit small enough to fit inside a distributor. An electronic control unit that fits inside a distributor is called an *electronic module* (Figure 11-21). Distributors that use an electronic module are usually called *integrated electronic distributors.*

The electronic module performs the same job as the externally mounted electronic control unit. A changing voltage from the distributor *pickup unit* is directed to the electronic module. The electronic module opens and closes the primary circuit in the ignition coil to provide the high secondary voltage.

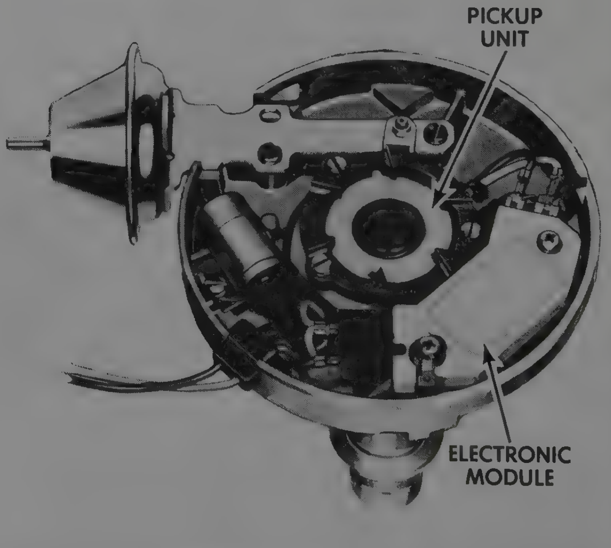


Figure 11-21. Integrated electronic distributor showing the electronic module and pickup unit. (Courtesy of Chevrolet Motor Division, General Motors Corporation)

AFTER-MARKET IGNITION SYSTEMS

Several types of after-market ignition systems are sold as replacement systems for vehicles which have breaker point distributors. Most of these are similar to electronic distributors. Two systems, however, operate differently: the **light-triggered ignition system** and the **capacitive discharge ignition system.**

The light-triggered ignition system (Figure 11-22) differs from the electronic system in the method used to trigger the ignition coil. A beam of infrared light is interrupted instead of a magnetic field. A rotating, toothed wheel called a *chopper* is used. By passing the teeth between a *light source* and an *infrared sensor*, a signal is produced for the electronic control unit. The electronic control unit controls the ignition coil just as it does in other electronic systems.

The capacitive discharge (abbreviated CD) ignition system utilizes the principle of storing and discharging energy from a condenser, or capacitor. (Detailed information was given earlier in this unit under the heading of "Condenser.") In a capacitive discharge ignition system, a charged capacitor is placed across the primary winding of the ignition coil. As the capacitor discharges into the primary winding, a strong magnetic field is established and cuts the secondary winding, inducing a high voltage. Energy is not stored in the secondary winding, but it acts to transform pulses of primary current to high-voltage secondary current. The energy developed in this way is considerably higher than that developed in a conventional ignition system. The capacitor is then disconnected from the ignition coil and recharged so that the discharge into the primary winding can occur again for the next firing cycle. The capacitor and charging components are located in an electronic control unit (Figure 11-23).

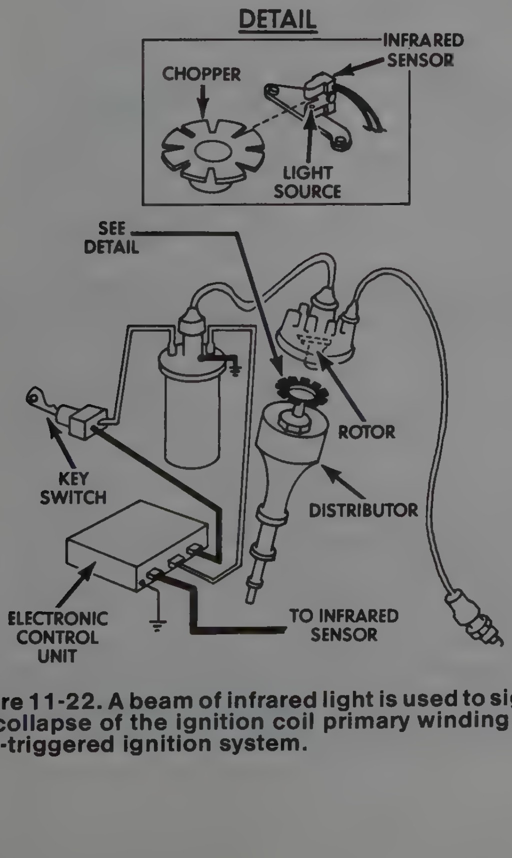


Figure 11-22. A beam of infrared light is used to signal the collapse of the ignition coil primary winding in a light-triggered ignition system.

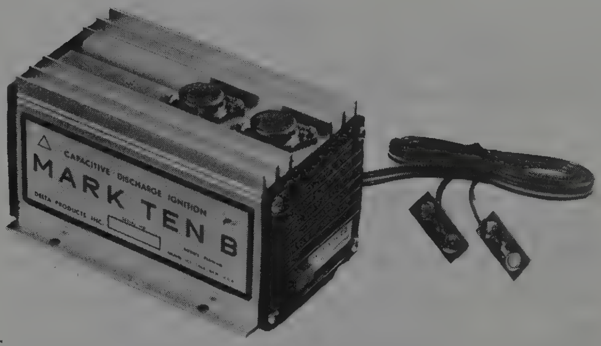


Figure 11-23. A capacitive discharge (CD) ignition system uses a capacitor and charging component mounted in an electronic control unit. (Courtesy of Delta Products, Inc.)

BALLAST RESISTOR

On early ignition systems, full battery voltage was applied to the ignition coil. The coil was designed to work on full battery voltage. This system had disadvantages, especially in cold weather. With the key switch, or ignition switch, in the START position and the starter motor cranking, battery voltage could drop excessively, producing a weak spark when a stronger spark was needed.

Most ignition systems use an ignition coil designed to operate on about 8 volts. When the engine is being cranked with the *key switch* in the START position, current flows to the *ignition coil* through a wire called the **bypass circuit** (Figure 11-24). This circuit goes around, or bypasses, the *ballast resistor*. During engine cranking, about 9 volts are supplied to the ignition coil. The voltage drop from 12 volts is due to the load caused by the starter motor. Once the engine starts, the voltage, with the alternator running, can go as high as 15 volts. To protect the ignition coil, a ballast resistor is installed in the circuit from the key switch to the

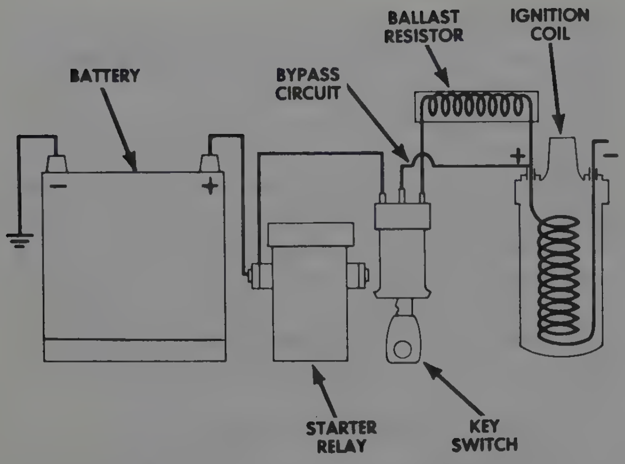


Figure 11-24. The ballast resistor protects the igntion coil from excessively high voltage.

ignition coil. When the engine is running, current must flow through the ballast resistor. The voltage is dropped to about 8 volts, which is the voltage the ignition coil is designed to operate on.

There are two general types of ballast resistors. One type has a *fixed resistance* regardless of temperature. The other has a *variable resistance* as temperature changes.

A fixed-resistance type of ballast resistor provides a certain amount of resistance regardless of temperature. This allows the ballast resistor to dissipate heat that may be generated in the ignition coil. It also reduces the effect of low temperatures on the primary winding. The ballast resistor used in most applications provides about 1.5 ohms of resistance, which represents approximately half of the primary circuit resistance. This means that half of the primary circuit resistance is unaffected by temperature changes. Most fixed-resistance ballast resistors are externally mounted near the ignition coil.

Other ignition systems use a variable-resistance type of ballast resistor, which varies in resistance according to temperature. At low engine RPM, the breaker points are closed for a relatively long period of time, causing the resistor to become very hot. The hotter the resistor is, the more it restricts the flow of current. As engine RPM is increased, the breaker points are closed for a much shorter period of time. This allows the ballast resistor to operate at a cooler temperature. The cooler the ballast resistor is, the less resistance it has. At higher engine speeds, it is desirable to have less resistance because there is less time for coil saturation (build-up of magnetic field). A ballast resistor may be an *externally mounted resistor* or it may be a *calibrated resistance wire* (Figure 11-25). Figure 11-26 shows a calibrated resistance wire in the external circuit of the ignition system. Computer-controlled ignitions can have the resistance regulated by the computer instead of by a resistor.

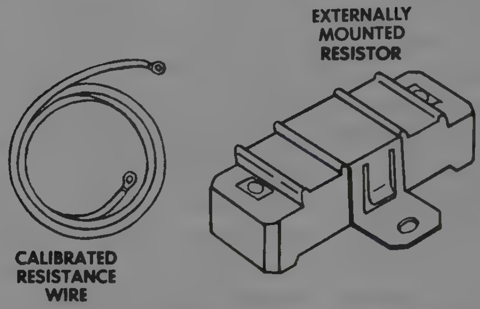


Figure 11-25. The ballast resistor may be an externally mounted unit or a calibrated resistance wire. (Courtesy of Delco Remy, Division of General Motors Corporation)

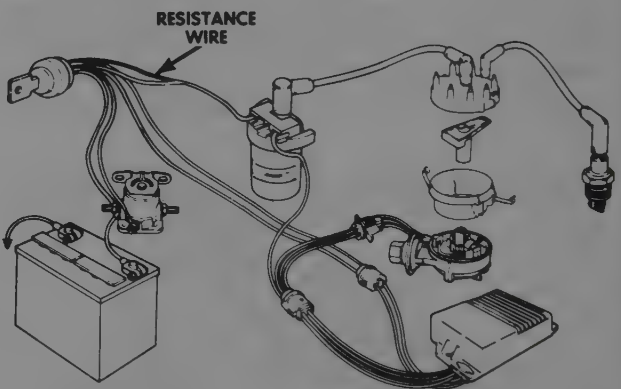


Figure 11-26. A calibrated resistance wire may be used in place of an externally mounted ballast resistor. (Courtesy of Ford Motor Company)

KEY TERMS

Breaker points: A mechanical switch used to open and close current flow to the coil primary winding.

Bypass circuit: The circuit that sends ignition current through a ballast resistor when the vehicle is running and bypasses the ballast resistor when the vehicle is cranked.

Capacitive discharge ignition system: An after-market ignition system that uses the energy stored in a capacitor to develop high voltage.

Condenser: An electrical storage device. It is also called a capacitor.

Electronic ignition distributor: A distributor that uses solid state components instead of breaker points to develop high-voltage current.

Ignition coil: An electrical device that transforms, or steps up, low battery voltage to a higher voltage for ignition.

Light-triggered ignition system: An after-market ignition system that uses a beam of infrared light to trigger the ignition coil.

Primary winding: That part of the ignition coil which consists of a few hundred turns of heavy wire and conducts low-voltage current.

Secondary winding: That part of the ignition coil which consists of thousands of turns of fine wire and conducts high-voltage current.

SELF-CHECK

1. List and describe the basic parts of an ignition system.
2. What is the purpose of the primary winding?
3. What is the purpose of the secondary winding?
4. Describe how induction is used to develop a high voltage.
5. What is the purpose of the distributor breaker points?
6. What happens in the ignition coil when the breaker points open?
7. What is the purpose of the capacitor or condenser?
8. Why does the distributor turn at half the engine speed?
9. Why is a ballast resistor required in an ignition system?
10. How does a transistor act like a mechanical switch?
11. What are some of the advantages of the electronic ignition distributor over the breaker point distributor?
12. How does an electronic control unit interrupt the primary circuit current?
13. What is the purpose of the electronic module in an integrated distributor?
14. How does a light-triggered ignition system work?
15. How does a capacitive discharge (CD) ignition system develop a secondary current?

DISCUSSION TOPICS AND ACTIVITIES

1. Use a cutaway ignition system to trace current flow through the ignition primary circuit.
2. Remove a condenser from a test engine distributor. Will the engine run? Why or why not?

CERTIFICATION PRACTICE

1. The distributor shaft and breaker cam are rotated at:
   A. One-third engine speed
   B. One-half engine speed
   C. Engine speed
   D. None of the above
2. High voltage is induced in the ignition coil:
   A. When the breaker points open
   B. When the breaker points close
   C. Both A and B
   D. Neither A nor B
3. Which of the following is part of a transistor:
   A. Base
   B. Emitter
   C. Collector
   D. All of the above
4. A transistor can be controlled with:
   A. A mechanical switch
   B. Circuit polarity
   C. Both A and B
   D. Neither A nor B
5. The integrated distributor primary circuit is interrupted by the:
   A. Electronic module
   B. Ignition pulse amplifier
   C. Magnetic chopper
   D. None of the above

ANSWERS

1: B, 2: A, 3: D, 4: C, 5: A

Unit 12

IGNITION SECONDARY CIRCUIT OPERATION

The purpose of the ignition secondary circuit is to take the high-voltage energy developed in the ignition coil secondary winding and deliver it as a spark in the engine's combustion chamber. The ignition secondary circuit consists of the ignition coil secondary circuit, distributor cap, rotor, spark plug cables (or wires), and spark plugs. The higher secondary voltage developed by an electronic ignition system makes servicing of the secondary circuit extremely important.

DEVELOPING JOB COMPETENCIES

When you finish reading and studying this unit, you should be able to:

- Trace the flow of current through an ignition secondary circuit.
- Describe the parts and operation of the distributor cap and the rotor.
- Explain the construction of high-voltage spark plug cables.
- Identify the parts of a unitized ignition distributor.
- Describe the parts and operation of spark plugs.

REVIEW OF SECONDARY CIRCUIT FUNDAMENTALS

When the breaker points open or the electronic control unit interrupts the primary current, a high voltage is induced in the ignition coil secondary winding. This is the beginning of the secondary circuit. Current leaves the *ignition coil* (Figure 12-1) through a high-voltage cable, sometimes called the *coil stinger*, into the *distributor cap*. From there, the current is transmitted through the *rotor* to *metal inserts* in the distributor cap which are connected to the *spark plug cables*. The rotor is mounted at the top of the *distributor shaft*. As the rotor turns from one metal insert to the next, it transmits its high-voltage current to each *spark plug* in firing order.

DISTRIBUTOR CAP AND ROTOR

The two main parts of the secondary circuit in the distributor are the *rotor* and the *distributor cap* (Figure 12-2). The distributor cap, which is usually made of an insulating material called Bakelite, fits over the *distributor housing* (Figure 12-3) and is retained by *hold-down screws* or

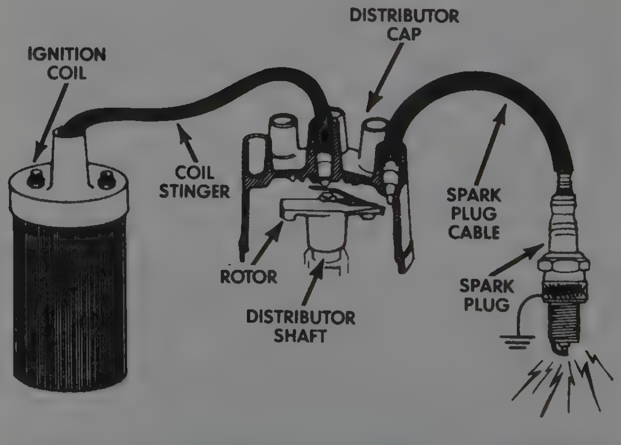


Figure 12-1. The secondary circuit begins in the ignition coil. (Courtesy of Sun Electric Corporation)

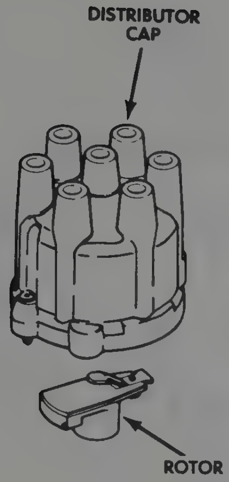

DISTRIBUTOR CAP
ROTOR

Figure 12-2. The secondary circuit parts of the distributor are the rotor and distributor cap. (Courtesy of American Motors Corporation)

spring clips. Metal inserts are cast into the *cap towers* to hold the distributor end of the spark plug cables. These metal inserts extend downward inside the cap to make electrical contact with the metal strip protruding from the *rotor*. A *slot* on the bottom of the cap matches a *built-up area* on the distributor housing. This ensures that the distributor cap can be installed in only one position.

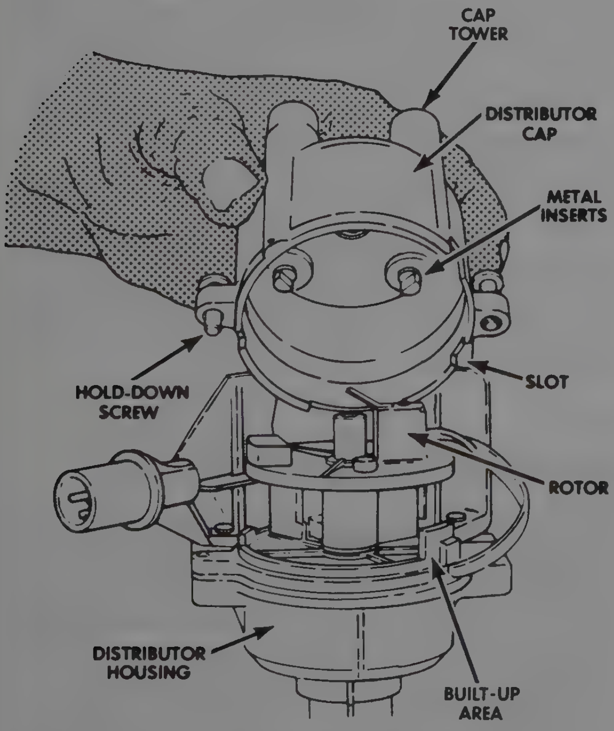

CAP TOWER
DISTRIBUTOR CAP
METAL INSERTS
HOLD-DOWN SCREW
SLOT
ROTOR
DISTRIBUTOR HOUSING
BUILT-UP AREA

Figure 12-3. Parts of the distributor cap and distributor housing. (Courtesy of Chrysler Corporation)

The distributor shaft and hole in the rotor are shaped, or keyed, so that the rotor can fit on the shaft in only one position. The rotor (Figure 12-4) is molded from an *insulated material*, usually Bakelite. A brass *contact strip* is attached to the top of the rotor. The contact strip is designed to contact the center insert in the distributor cap. The contact strip extension protrudes from the end of the rotor and is called the *rotor blade*. It is used to transfer high-voltage current to the distributor's metal inserts. Rotors come in many shapes, but they all have the same basic parts (Figure 12-5).

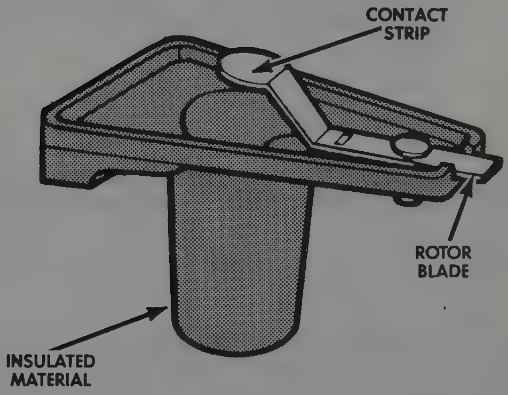

CONTACT STRIP
ROTOR BLADE
INSULATED MATERIAL

Figure 12-4. Parts of a rotor. (Courtesy of American Motors Corporation)

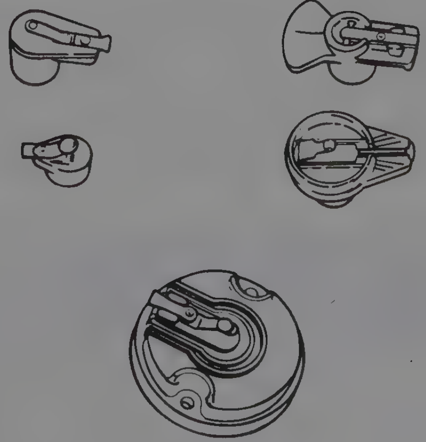


Figure 12-5. There are many different shapes of rotors, but they all have the same basic parts. (Courtesy of Delco Remy, Division of General Motors Corporation)

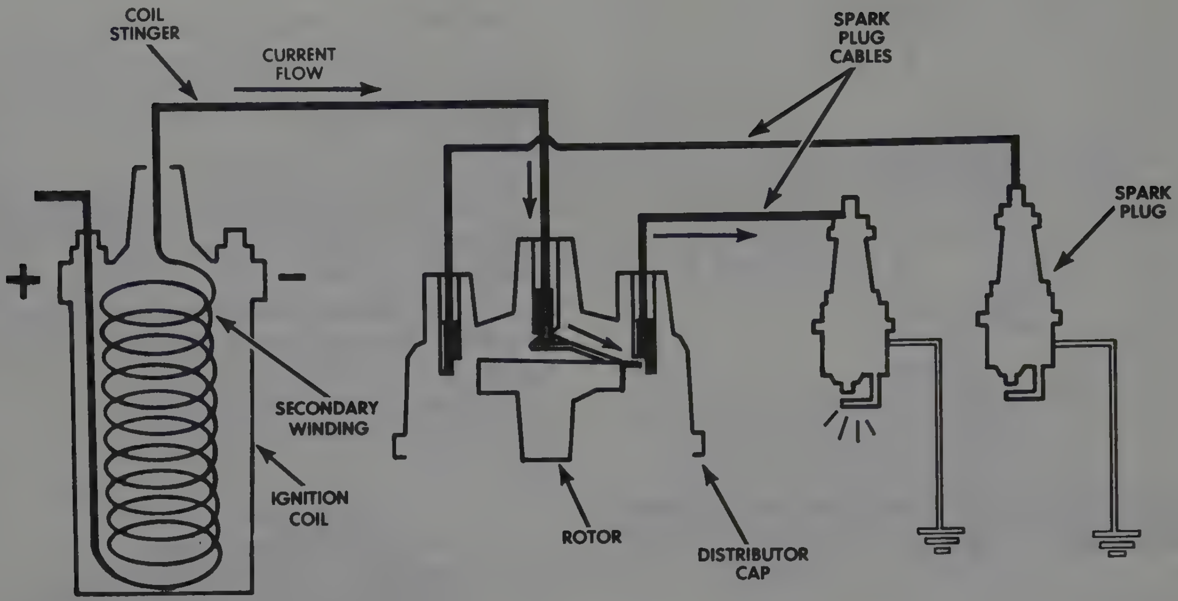


Figure 12-6. Secondary current flows from the ignition into the distributor cap, across the rotor, into the spark plug cable, and to the spark plug. (Courtesy of Chevrolet Motor Division, General Motors Corporation)

The operation of the *distributor cap* and *rotor* is shown in the wiring diagram of Figure 12-6. When a high-voltage current is induced in the *secondary winding*, it is directed through the high-voltage *coil stinger* into the center tower of the distributor cap. The high-voltage current flows down the center cap insert. The insert is in contact with the rotor contact strip so that high-voltage current flows into the rotor blade. From here, current travels through the *spark plug cable* to the *spark plug*, developing a spark in the combustion chamber.

NOTE: The rotor blade does not actually touch the metal inserts. There is always an air gap between the end of the rotor blade and the metal inserts. This air gap is usually set so that no more than 2,000 to 3,000 volts are required to carry the current across the gap in the form of a spark.

The distributor cap has a tower and metal insert for each engine cylinder. The distributor is installed in the engine so that the rotor will align itself with the correct metal insert for the appropriate cylinder when that cylinder is ready for a power stroke. (Depending upon the camshaft rotation and distributor gearing, the rotor turns clockwise or counterclockwise.)

The spark plug cables are arranged in the distributor cap so that as the rotor turns, they deliver high-voltage current to the cylinders in their firing order. A four-cylinder engine with a firing order of 1, 3, 4, and 2 is shown in Figure 12-7. The rotor is in position to deliver high-voltage current to cylinder No. 1. As the rotor turns, it next aligns with the metal insert for cylinder No. 3, then 4, and then 2. The spark is thus delivered to each cylinder when it is ready for a power stroke.

The distributor executes its fuction of firing all cylinders for each revolution of the rotor. The four-stroke-cycle principle requires 720° of crankshaft travel, or two revolutions, in order to fire all the engine's cylinders. Therefore, the distributor shaft turns once for every two crankshaft revolutions.

SPARK PLUG CABLES

Spark plug cables, or wires, carry the high-voltage secondary current from the distributor cap to each of the spark plugs. Spark plug cables are also referred to as secondary wires, spark plug leads, or high tension wires.

Essentially, a spark plug cable is a core of conducting material enclosed in an insulator. Older vehicles used a metal core made from copper or stainless steel. Metal conductor spark

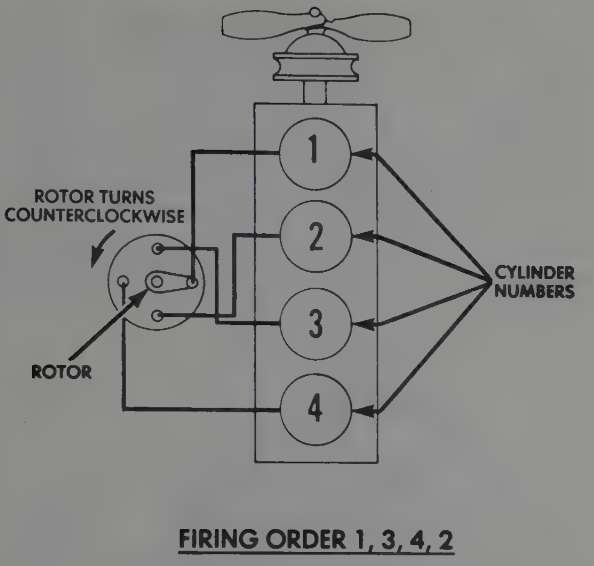

ROTOR TURNS COUNTERCLOCKWISE
ROTOR
1
2
3
4
CYLINDER NUMBERS
FIRING ORDER 1, 3, 4, 2

Figure 12-7. As the rotor turns, it delivers high-voltage current to each cylinder in its firing order.

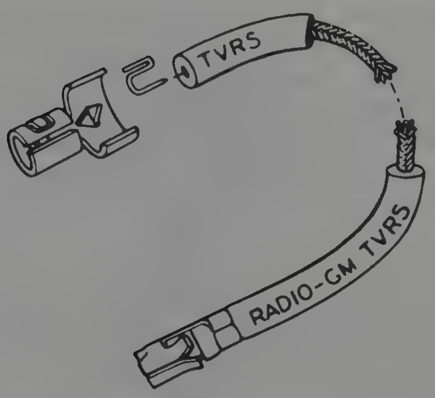

TVRS
RADIO-GM TVRS

Figure 12-8. Radio frequency interference is eliminated with TVRS spark plug cables. (Courtesy of Delco Remy, Division of General Motors Corporation)

plug cables contribute substantially to what is known as **radio frequency interference**, abbreviated RFI. RFI presents a problem for various forms of communication equipment such as those used in community service vehicles (police cars, fire trucks, and ambulances).

To prevent spark plug cables from creating RFI, a new design was implemented. The letters **TVRS** (Figure 12-8) on a spark plug cable indicate that it is designed to eliminate RFI. A cutaway view of this type of spark plug cable is shown in Figure 12-9. The *conducting material* is carbon-impregnated fiberglass. Layers of *reinforcement* (fiberglass or glass braid) and *insulation* are added to prevent current leakage and add strength to the cable. There is also a *high-conductive electro-coating* for firm contact. The *outer jacket* of most cables is made of Hypalon or silicone rubber to make the cable flexible and extremely heat-resistant. The outer diameter of the spark plug cable is specified in millimeters (mm). Most ignition systems use a spark plug cable that is 8 mm in diameter.

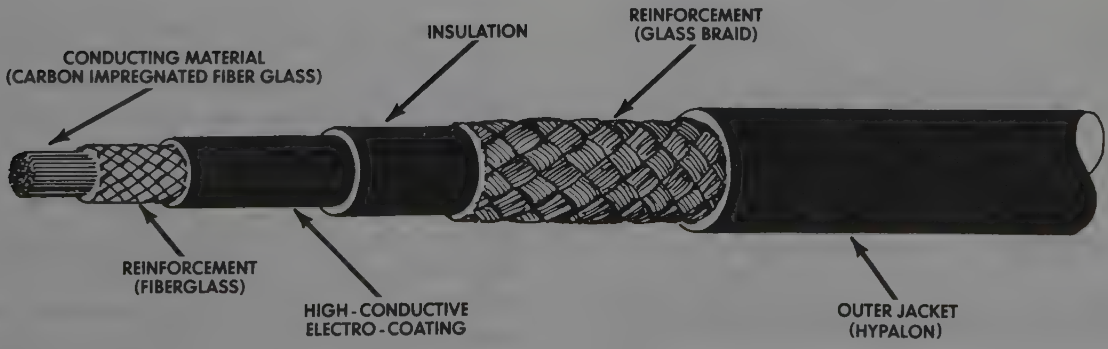

CONDUCTING MATERIAL (CARBON IMPREGNATED FIBER GLASS)
INSULATION
REINFORCEMENT (GLASS BRAID)
REINFORCEMENT (FIBERGLASS)
HIGH-CONDUCTIVE ELECTRO-COATING
OUTER JACKET (HYPALON)

Figure 12-9. Typical construction of a spark plug cable. (Courtesy of Belden Corporation)

The parts of a typical *spark plug cable* and the way they are connected to the *distributor cap* and *spark plug* are shown in Figure 12-10. A *metal terminal* is attached to both ends of the spark plug cable. One terminal is designed to fit into the distributor cap, the other over the spark plug terminal. After the terminal is installed in the distributor cap, a *sealing nipple* fits over the distributor cap tower to seal out moisture. A *boot* fits over the spark plug to help insulate and seal the connection. Boots are available in a variety of sizes and shapes (Figure 12-11).

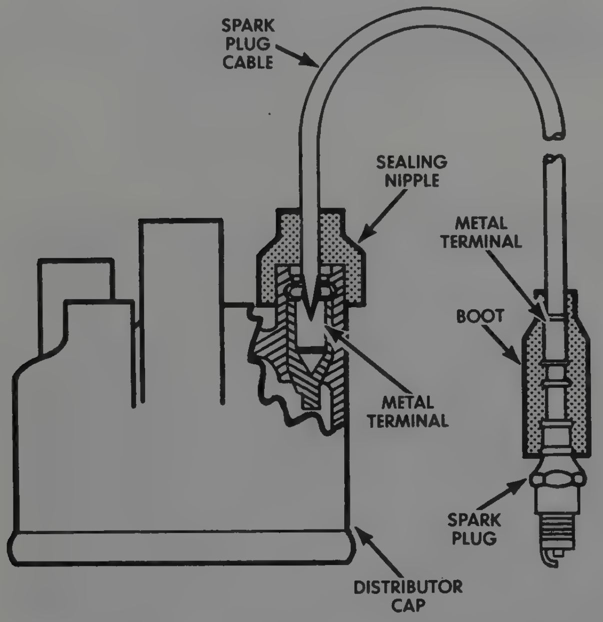


Figure 12-10. Spark plug cable parts and their connection to the spark plug and to the distributor cap.

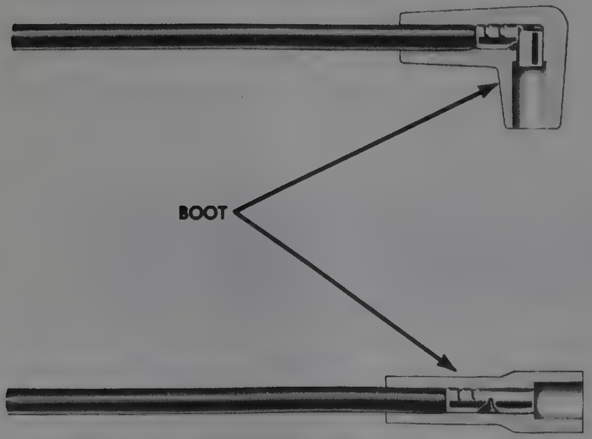


Figure 12-11. Boots are available in a variety of shapes. (Courtesy of Belden Corporation)

The spark plug cables are routed to each of the cylinders using insulated *holders* (Figure 12-12) to prevent the cables from touching each other. If the cables touched, voltage from one cable could enter another, resulting in the wrong cylinder receiving ignition — a process called *cross fire*. It is also important to prevent the spark plug cables from contacting a hot exhaust manifold, which would damage the insulation.

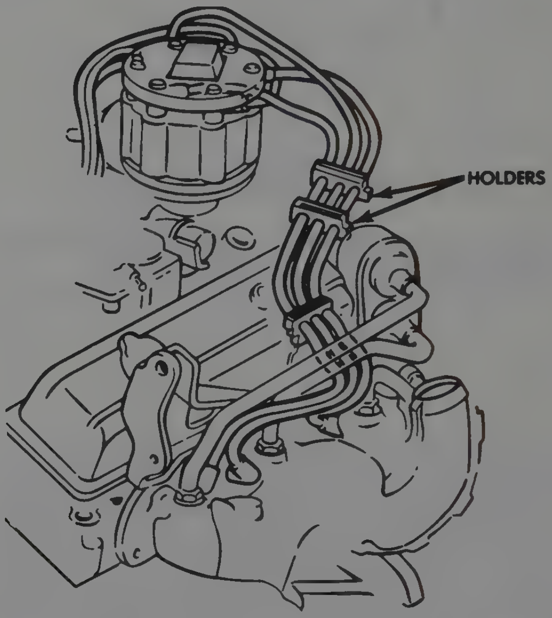


Figure 12-12. Spark plug cables are routed through holders to prevent cross fire and damage from a hot exhaust manifold. (Courtesy of Chevrolet Motor Division, General Motors Corporation)

UNITIZED IGNITION DISTRIBUTOR

It is possible to combine the ignition coil and distributor into one assembly. This type of ignition distributor is called a *unitized ignition distributor* (Figure 12-13). It is somewhat larger than most conventional distributors. With over 35,000 volts being developed, an increase in size is necessary to widen the space that must exist between the distributor cap metal inserts. A widened space prevents high-voltage arcing between the metal inserts and prevents current leakage to ground.

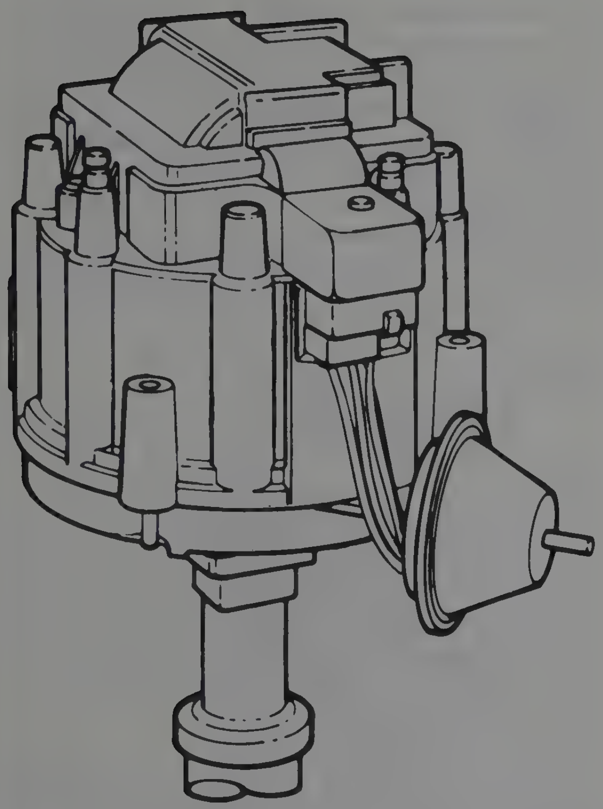


Figure 12-13. An ignition coil and distributor combined into one assembly is called a unitized ignition distributor. (Courtesy of American Motors Corporation)

The ignition coil is housed between the *cover* and *distributor cap* (Figure 12-14). With the ignition coil built into the distributor, the need for mounting and wiring a separate ignition coil is eliminated. The distributor cap, along with the ignition coil and cover, is held against the *distributor housing* with *spring-loaded latches*.

When completely assembled, an *electrical connector* with latches connects the electrical components in the distributor housing to the *ignition coil terminals*. There is also a *slip-type terminal* in the electrical connector to which a tachometer can be connected.

SPARK PLUGS

The primary function of the spark plug is to provide a spark to ignite the compressed air-fuel mixture inside the *combustion chamber* (Figure 12-15).

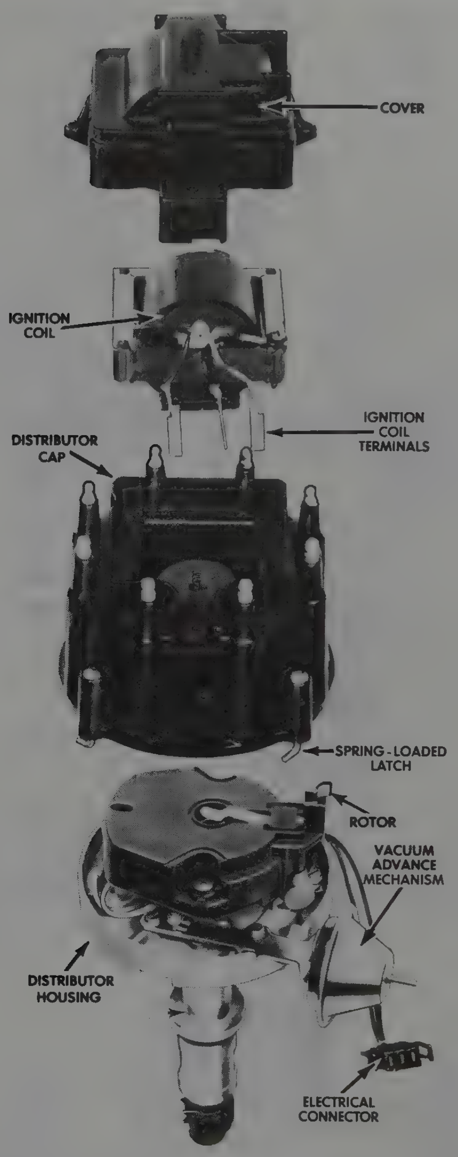

COVER
IGNITION COIL
IGNITION COIL TERMINALS
DISTRIBUTOR CAP
SPRING-LOADED LATCH
ROTOR
VACUUM ADVANCE MECHANISM
DISTRIBUTOR HOUSING
ELECTRICAL CONNECTOR

Figure 12-14. Exploded view of a unitized ignition distributor. (Courtesy of Chevrolet Motor Division, General Motors Corporation)

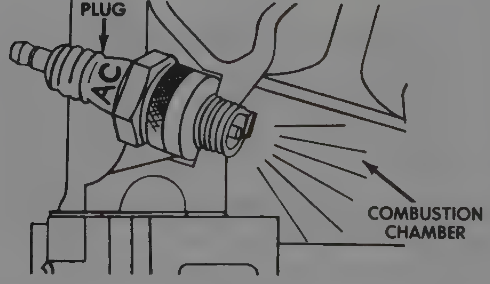

SPARK PLUG
AC
COMBUSTION CHAMBER

Figure 12-15. The spark plug creates the spark that ignites the air-fuel mixture in the combustion chamber. (Courtesy of Delco Remy, Division of General Motors Corporation)

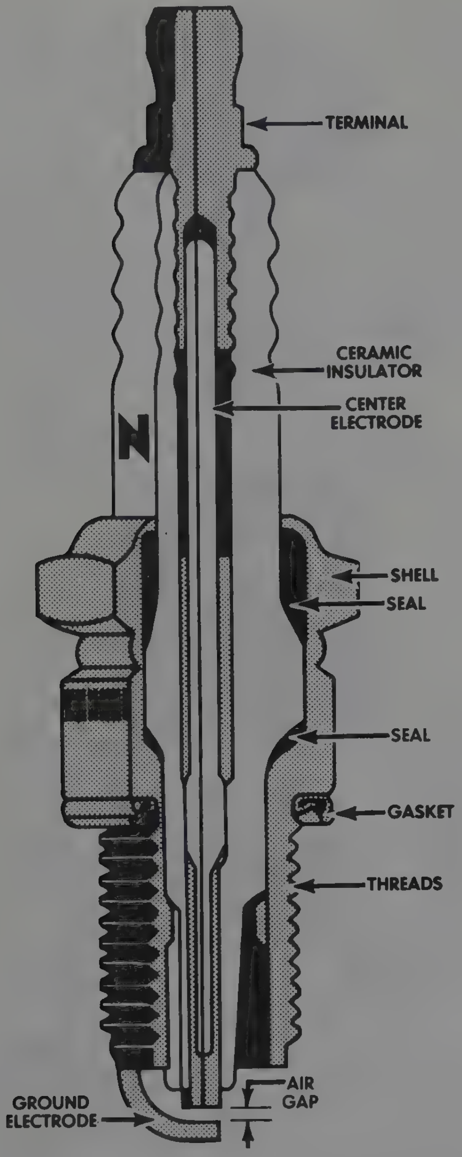


Figure 12-16. Cross section of a spark plug. (Courtesy of NGK Spark Plugs U.S.A., Inc.)

Spark Plug Construction

The parts of a spark plug are shown in Figure 12-16. The top part of the spark plug has a *terminal* to which the spark plug cable is connected. The terminal is connected to a wire called a *center electrode* that goes through the middle of the spark plug. The center electrode provides a path for high-voltage current.

The high-voltage current must not be allowed to escape or leak away. Leakage is prevented by a ribbed *ceramic insulator* that fits around the center electrode. A metal housing called a *shell* makes up the bottom of the spark plug. The shell has *threads* that allow the spark plug to be threaded into the cylinder head. Also, the shell has hex-shaped flats to allow spark plug sockets and ratchets to be used for installation and removal.

A **ground electrode**, also called a *side electrode*, is connected to ground through the shell. It is placed a small distance away from the center electrode. This distance is the **spark plug gap**, or *air gap*, that the current jumps to create a spark.

The spark plug is subjected to the high pressures of the combustion chamber. *Seals* are used between the shell and ceramic insulator, and between the center electrode and the ceramic insulator, to prevent the leakage of this pressure. A copper or aluminum *gasket* is also used to prevent leakage of combustion pressure from around the shell threads. (Some spark plugs have a special tapered seat instead of a gasket.)

Many spark plugs are manufactured with a resistor in the center electrode. The resistor prolongs spark plug service by reducing electrode erosion. The resistor spark plug also provides freedom from annoying electrical interference (on-board radio interference).

Spark Plug Operation

High-voltage current enters the spark plug at the terminal end of the center electrode and flows down the center electrode to the air gap. The current overcomes the resistance of the air gap and air-fuel mixture and jumps to the ground electrode. The spark created as the current jumps ignites the air-fuel mixture.

The voltage required to overcome the resistance of the air gap and the air-fuel mixture differs under different engine operating conditions. The wider the air gap, the higher the required voltage will be. The condition of the spark plug electrodes also is very important. Much less voltage is required to jump from clean electrodes than from dirty, eroded ones.

To help reduce exhaust emissions, car manufacturers have developed engines that operate on lean air-fuel mixtures. However, standard air gap of .035" (Figure 12-17) used in previous years proved too narrow to properly ignite the leaner air-fuel mixture. To allow for more arc (spark) exposure to the air-fuel mixture, and thus improve the ignition process, the spark plug gap was widened to measurements ranging from .044" to .080".

CAUTION: Do not attempt to widen the air gap on conventional plugs. Such an attempt would cause the ground electrode to be positioned at an angle to the center electrode. This would cause improper wear, which could result in starting problems or premature misfiring.

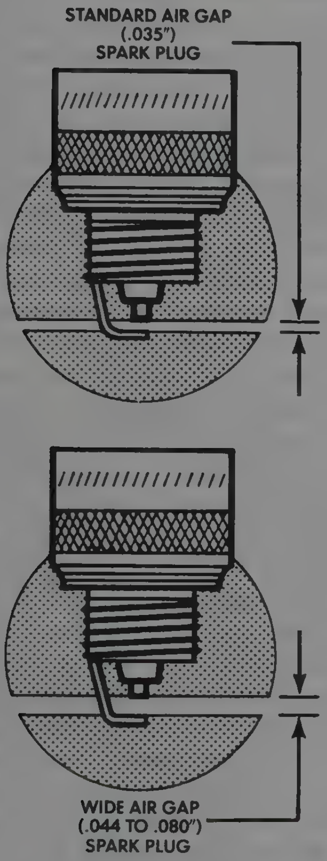


Figure 12-17. Wide air gap spark plugs have replaced standard air gap spark plugs on many late-model cars.

Spark Plug Sizes

For a spark plug to work properly, it must be the correct size for the combustion chamber into which it is installed. Different sizes of spark plugs are required for different engine designs. Spark plugs are made with different shell thread diameters (Figure 12-18). The threads are made in metric sizes measured in millimeters.

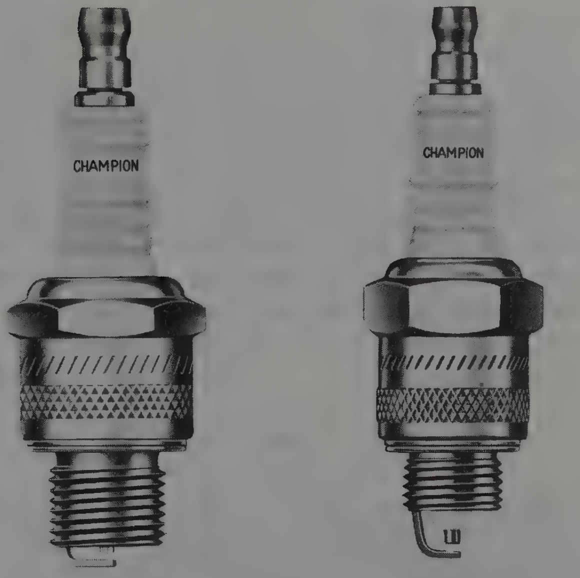


Figure 12-18. Spark plugs are manufactured with threads of different diameters.

The threaded section of the shell, called the **reach**, is also made in different lengths. Figure 12-19 shows two of the several reach dimensions manufactured.

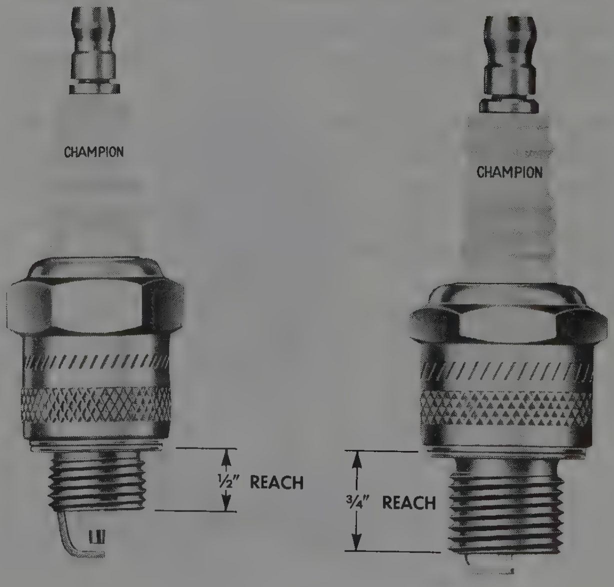


Figure 12-19. Spark plugs are manufactured with different reaches.

The combustion chamber design determines what length reach is necessary. If an incorrect reach is used (Figure 12-20), a number of problems may result. If the reach is too long, the firing end may be hit by the piston, or the excessively projected firing end may overheat, resulting in engine damage. If the reach is too short, engine power may be decreased, and the thread of the cylinder head may be clogged by accumulated deposits. Also, it may be difficult to install a spark plug with proper reach afterwards.

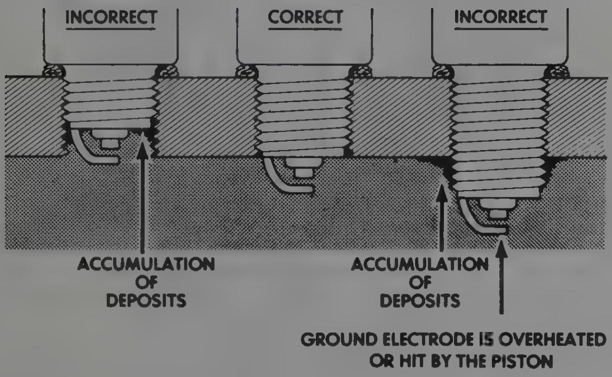


Figure 12-20. Common problems associated with incorrect reach. (Courtesy of NGK Spark Plugs U.S.A., Inc.)

Spark Plug Heat Range

The spark plug tip (firing end, or electrode area), exposed in the engine's combustion chamber, is subjected to temperatures that may exceed 2,000° F. The firing end is designed to remove this heat through the engine's cylinder head. The path of heat flow away from the firing end is shown in Figure 12-21. Heat moves up the ceramic insulator to the metal shell and then out into the engine's cylinder head.

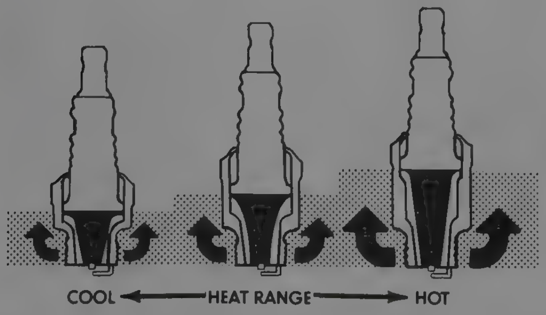


Figure 12-21. Heat flows away from a spark plug firing end.

Spark plugs are designed to operate within a specific heat range. The term **heat range** describes the ability of a spark plug to conduct heat away from the firing end. The heat range of a spark plug is determined by the distance the heat must flow from the firing end to the shell. This in turn is determined by the length of the insulator firing end. If the path is a long one, the firing end will remain at a high temperature, and the spark plug is referred to as a *hot spark plug*. If the path for heat flow is short, heat is removed more easily from the firing end, and the spark plug is cooler in operation. This type of spark plug is referred to as a *cold spark plug*. The heat paths for a cold spark plug and a hot spark plug are shown in Figure 12-22.

Engines generally require a cold spark plug to meet temperature requirements during full-power operation. These engines, however, develop only a fraction of their potential power during slow, start-and-stop operation, which makes a hot spark plug more desirable. To remedy this problem, many spark plugs are designed with an insulator tip that extends beyond the edge of the shell. These spark plugs are called *extended-tip, power-tip,* or *self-cleaning* spark plugs. In Figure 12-23, this type of spark plug is compared with a conventional-tip spark plug.

Extended-tip design provides a longer insulator tip on the spark plug, which in turn provides a longer fouling path. The fouling path is the area that would have to be filled with carbon to create an electrical path. Most carbon build-up is subsequently cleaned by the swirling gases in the combustion chamber (Figure 12-24). The tip temperature of extended-tip spark plugs is higher than that of conventional-tip spark plugs during light-load, low-speed

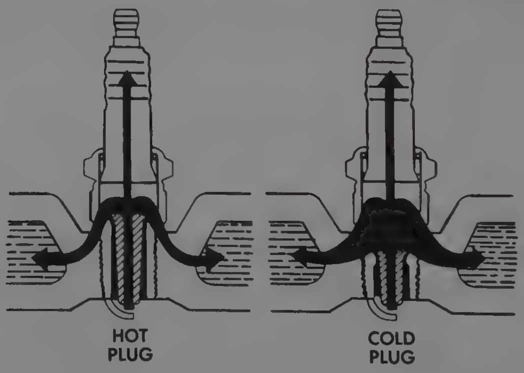


Figure 12-22. Heat flow has a longer path for a hot spark plug than for a cold one. (Courtesy of NGK Spark Plugs U.S.A., Inc.)

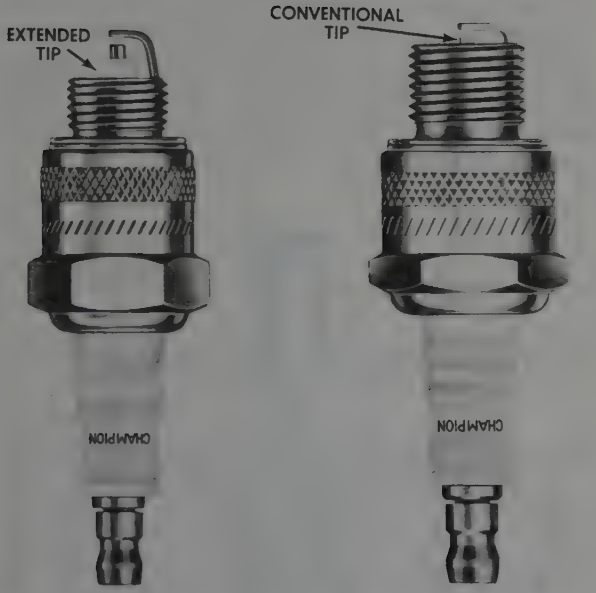


Figure 12-23. Extended-tip spark plug and conventional-tip spark plug.

operation. This enables the spark plug to burn off combustion deposits. Under wide-open throttle conditions and engine speeds in excess of 2,000 RPM, however, the tip temperature of extended-tip spark plugs is lower than that of conventional-tip spark plugs. The lower temperature is created by the incoming air-fuel mixture passing over the insulator tip and cooling it during each intake stroke (Figure 12-24). The cooling effect is even more evident at higher speeds and heavier loads because of the greater velocity of the incoming air-fuel mixture.

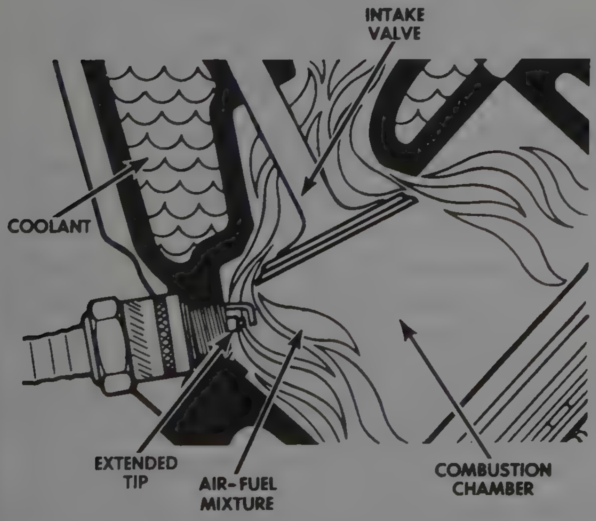


Figure 12-24. Cleaning and cooling action of the air-fuel mixture on an extended-tip spark plug in a combustion chamber.

The extended-tip spark plug combines the advantages of both hot and cold spark plugs. It satisfies the demands imposed by heavy traffic conditions and also provides the cooler temperatures needed during high-speed operation.

Spark Plug Codes

In order to be correctly matched to an engine, a spark plug must have the correct thread diameter, gasket (or tapered seat), heat range, electrode tip, and reach. Spark plug manufacturers identify these items on their spark plugs with a **spark plug code**. The code is printed on the ceramic insulator of the spark plug (Figure 12-25).

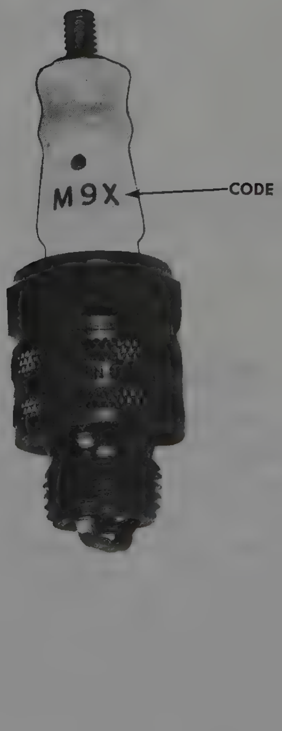


Figure 12-25. Spark plugs are matched to the engine with a code printed on the ceramic insulator.

Spark plug codes vary according to manufacturer. The code symbols are usually explained in the manufacturer's catalog. A typical spark plug code chart is shown in Figure 12-26.

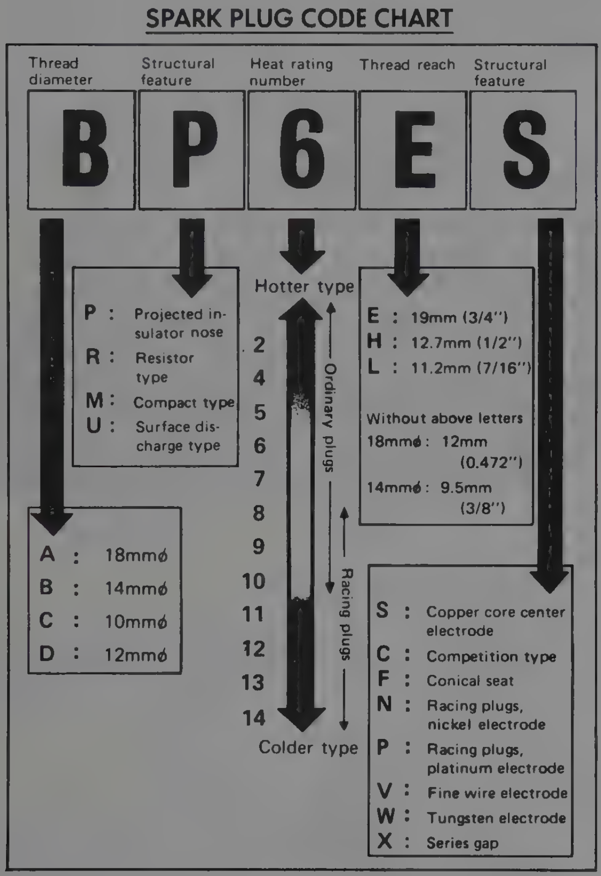

SPARK PLUG CODE CHART
Thread diameter
Structural feature
Heat rating number
Thread reach
Structural feature
B
P
6
E
S
P : Projected insulator nose
R : Resistor type
M : Compact type
U : Surface discharge type
A : 18mmø
B : 14mmø
C : 10mmø
D : 12mmø
Hotter type
2
4
5
6
7
8
9
10
11
12
13
14
Colder type
Ordinary plugs
Racing plugs
E : 19mm (3/4")
H : 12.7mm (1/2")
L : 11.2mm (7/16")
Without above letters
18mmø : 12mm (0.472")
14mmø : 9.5mm (3/8")
S : Copper core center electrode
C : Competition type
F : Conical seat
N : Racing plugs, nickel electrode
P : Racing plugs, platinum electrode
V : Fine wire electrode
W : Tungsten electrode
X : Series gap

Figure 12-26. Typical spark plug code chart. (Courtesy of NGK Spark Plugs U.S.A., Inc.)

IGNITION POLARITY

Ignition systems are designed with an **ignition polarity** [positive (+) and negative (−)], so that the spark fires (jumps) from the hotter center electrode to the colder ground electrode of the spark plug. If the battery cables or ignition coil leads are reversed, the polarity [positive (+) and negative (−)] will be reversed, forcing the spark plugs to fire from the ground electrode to the center electrode. In such a case, more voltage is required to fire the spark plugs. The high-voltage current available from the ignition coil may not be enough to ignite the air-fuel mixture.

Most vehicles presently use a 12-volt, negative-ground battery and ignition system. Leads from the ignition coil should be connected as shown in Figure 12-27. The negative (−) lead should always be connected to the distributor to prevent reversed polarity.

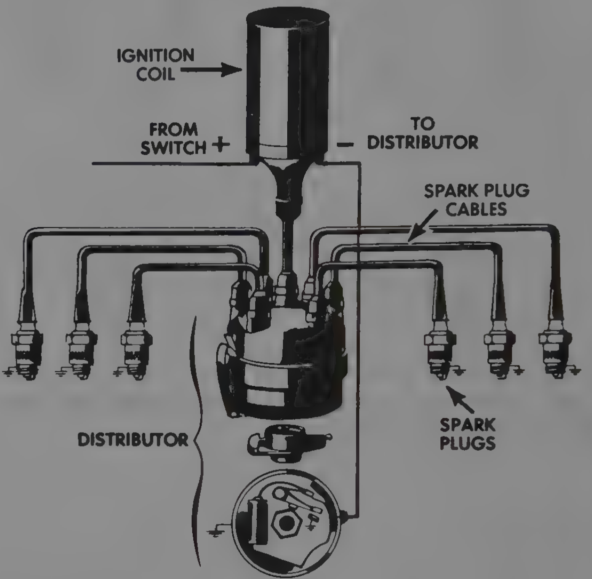

IGNITION COIL
FROM SWITCH +
− TO DISTRIBUTOR
SPARK PLUG CABLES
DISTRIBUTOR
SPARK PLUGS

Figure 12-27. The polarity is correct when the negative (-) ignition coil primary lead is connected to the distributor.

KEY TERMS

Ground electrode: The spark plug electrode that is connected to ground and sometimes called the side electrode.

Heat range: The ability of a spark plug to conduct heat away from its firing end.

Ignition polarity: The polarity [positive (+) and negative (−)] which ensures that the spark fires (jumps) from the center electrode to the ground electrode.

Radio frequency interference: Electrical interference with communications equipment associated with metal conductor spark plug cables. It is abbreviated RFI.

Reach: The threaded section of the spark plug shell that determines how far the spark plug fits into the combustion chamber.

Spark plug code: A code printed on the ceramic insulator plug to describe its technical features and application.

Spark plug gap: The distance that the secondary current jumps to create a spark.

TVRS: Letters on a spark plug cable indicating a design that eliminates RFI.

SELF-CHECK

1. What is the purpose of the secondary circuit?
2. Where is secondary voltage developed?
3. What is the purpose of the distributor cap and rotor?
4. Why are the distributor cap and rotor made of insulating material?
5. What does TVRS stand for on a spark plug cable?
6. What does RFI stand for and why is it a problem?
7. Why is the careful routing of spark plug cables important?
8. What is the purpose of a spark plug?
9. What is the air gap, or spark plug gap, used for?
10. What is spark plug reach?
11. What is spark plug heat range?
12. What is the advantage of an extended-tip spark plug?
13. What information may be found in a spark plug code?
14. Why is ignition polarity important?

DISCUSSION TOPICS AND ACTIVITIES

1. Use a cutaway ignition system to trace the flow of ignition secondary current from the ignition coil to the spark plug.
2. Collect a variety of used spark plugs from around the shop. How many different design features can you identify?

CERTIFICATION PRACTICE

1. The spark plug cables in the distributor cap are routed according to:
   A. Firing order
   B. Cylinder number
   C. Rotor rotation
   D. All of the above
2. Spark plug cables are routed through holders to the spark plugs:
   A. To prevent cross fire
   B. To prevent damage to the cable insulation
   C. Both A and B
   D. Neither A nor B
3. The spark plug side of ground electrode is attached to the:
   A. Shell
   B. Ceramic insulator
   C. Terminal
   D. None of the above
4. A 12-volt, negative-ground automobile has the proper ignition polarity if:
   A. The negative (−) coil lead is connected to the distributor
   B. The positive (+) coil lead is connected to the distributor
   C. Both A and B
   D. Neither A nor B
5. The sizes 1/2" and 3/4" refer to a spark plug's:
   A. Thread diameter
   B. Reach
   C. Shell wrench flats
   D. None of the above

ANSWERS

1: D, 2: C, 3: A, 4: A, 5: B

Unit 13

IGNITION ADVANCE SYSTEMS

The ignition system must not only develop and distribute high-voltage sparks to each cylinder, it must also "time" the spark to occur at the proper instant to start the combustion process. Proper timing ensures that the fuel will burn completely. The length of time necessary to burn the fuel varies with engine speed and load. To compensate for these factors, distributors are equipped with speed and load spark advance sensing mechanisms or systems.

DEVELOPING JOB COMPETENCIES

When you finish reading and studying this unit, you should be able to:

- List and explain the factors which affect combustion time in the combustion chamber.
- Describe how basic timing is established and how it is changed.
- Describe the parts and operation of the speed-sensing centrifugal advance mechanism.
- Describe the parts and operation of the load-sensing vacuum advance mechanism.
- Describe the operation and explain the purpose of computer-controlled timing.
- Describe the operation of a dual breaker point distributor and a dual pickup distributor.

COMBUSTION

Contrary to a common misunderstanding, **combustion** is not an explosion within the combustion chamber, but rather a burning process. The air-fuel mixture starts to burn at the ignition spark. The flame progressively radiates out from the spark plug until it is limited by the walls of the combustion chamber and piston. This sequence of events is shown in Figure 13-1. The flame travels much like a dry grass fire, only faster. Since combustion takes time, the air-fuel mixture must be ignited early enough for the combustion process to be completed at the desired time.

NOTE: It is important that combustion be completed at the proper time. Maximum pressures are reached the instant combustion is completed. The crankshaft must be ready to receive this pressure.

When the *piston* is at TDC (top dead center), the *crankshaft* and *connecting rod* form a vertical line (Figure 13-2). The crankshaft forms an angle with respect to this vertical line when the piston is positioned before or after TDC (refer again to Figure 13-2). This angle, measured in degrees, is the method used to describe when ignition occurs. The letters BTDC are used to describe angles before top dead center and ATDC to describe angles after top dead center.

When combustion pressures are developed on top of the piston, the crankshaft must be in a position to convert as much of this pressure into mechanical rotating energy as possible. Four crankshaft positions are shown in Figure 13-3. Position A is early and therefore not efficient, because the combustion pressure is actually working against crankshaft rotation. Position B is also considered early. It does not

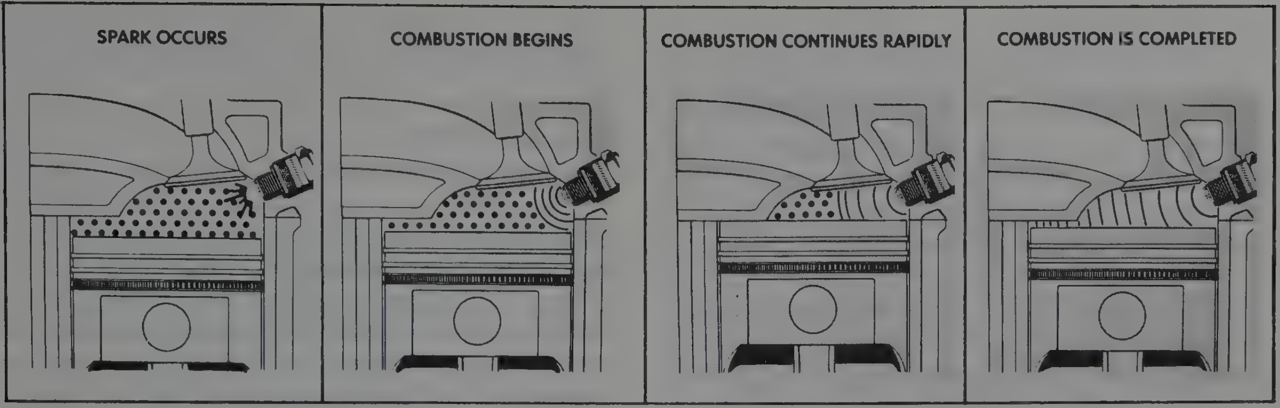

SPARK OCCURS
COMBUSTION BEGINS
COMBUSTION CONTINUES RAPIDLY
COMBUSTION IS COMPLETED

Figure 13-1. Combustion is a burning process that results in a steady, even flame front that moves across the combustion chamber.

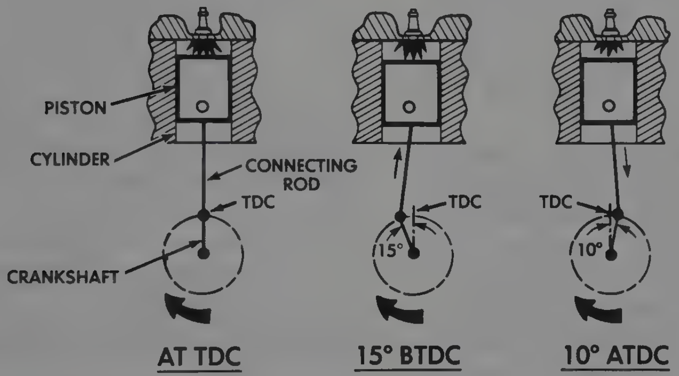

PISTON
CYLINDER
CONNECTING ROD
TDC
CRANKSHAFT
15°
TDC
TDC
10°
AT TDC
15° BTDC
10° ATDC

Figure 13-2. When the piston is at TDC, the crankshaft and connecting rod form a vertical line. When the piston is positioned before or after TDC, an angle is formed with respect to this vertical line.

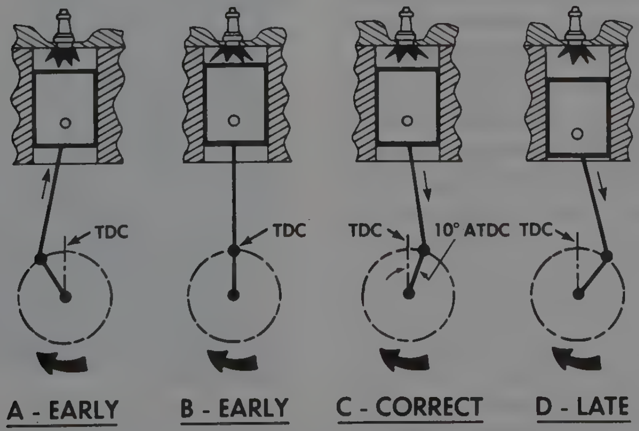

TDC
TDC
TDC
10° ATDC
TDC
A - EARLY
B - EARLY
C - CORRECT
D - LATE

Figure 13-3. The crankshaft must be in the correct position to take advantage of the pressure of combustion.

give the greatest possible efficiency from the combustion pressure, because its peak force is applied down through the crankshaft connecting rod journals to the main bearings. Combustion pressures can be most efficiently converted to mechanical energy at approximately 10° ATDC, shown in Position C. Position D does not take advantage of peak pressure and is considered late. The expanding gases are not as effective in Position D, because the crankshaft has rotated too far past TDC, and the effective power stroke is shortened. As a result, much of the usable combustion heat escapes from the exhaust valve during the exhaust stroke.

The time required for combustion varies according to changes in engine operation. The most important factors affecting combustion time are:

1. *Engine speed:* At a low engine speed, there is sufficient time to introduce a spark and burn the air-fuel mixture completely. At higher engine speeds, however, there is less time for the air-fuel mixture to burn.
2. *Engine load:* When engine load is heavy (as when the vehicle is under rapid acceleration or climbing a hill), the throttle is wide open and the air-fuel mixture is tightly packed in the cylinder. Under these conditions, combustion in the cylinder is fairly rapid. When engine load is light (as when the vehicle is operating on a level road), the throttle is open less far and the air-fuel mixture is packed less tightly. Under these conditions, combustion is slower.
3. *Engine operating temperature:* Combustion is faster when the engine heats up to operating temperature than when the metal of the combustion chamber is cold.
4. *Engine design:* Several engine design features such as combustion chamber shape, spark plug position, and cylinder bore diameter affect the rate of combustion.
5. *Fuel characteristics:* When gasoline with a high octane rating is used, combustion is slower than when gasoline with a low octane rating is used. The more volatile the gasoline, the more quickly it burns.

TIMING SYSTEMS

The purpose of the ignition timing system is to regulate the time that ignition is introduced into the combustion chamber in accordance with engine operating conditions. Changing the ignition timing is a function of the distributor.

Basic Timing

The ignition timing established by the position of the distributor in the engine is the **basic timing.** The distributor shaft is engaged with and driven by the engine camshaft. The *reluctor* or the *breaker cam,* depending on the type of distributor, is attached to the distributor *shaft* (Figure 13-4). The *pickup unit* or *breaker point assembly* is mounted inside the distibutor housing.

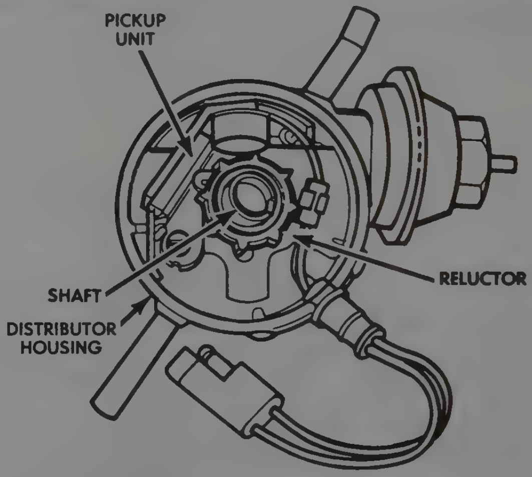


Figure 13-4. Reluctor and shaft of an elctronic ignition distributor. (Courtesy of Chrysler Corporation)

The distributor is held in position on the engine by a *hold-down bolt and clamp assembly* (Figure 13-5). When the hold-down bolt is loosened, the distributor can be rotated with respect to the reluctor or breaker cam. Rotating the distributor in the opposite direction from reluctor rotation causes the pickup unit signal

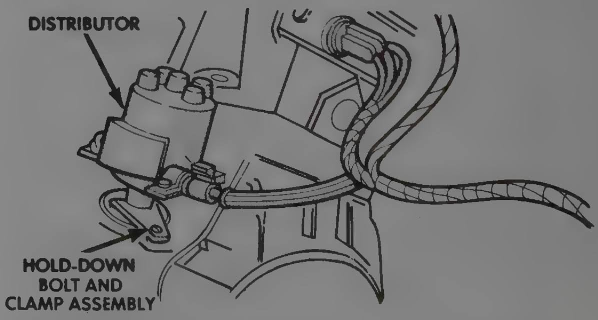


Figure 13-5. The distributor is held in position by a hold-down bolt and clamp assembly. (Courtesy of Chrysler Corporation)

to be sent sooner. This in turn causes ignition to be advanced, or to occur sooner in each of the cylinders. Moving the distributor in the same direction as reluctor rotation causes the signal to be sent later. This in turn causes ignition to be retarded, or to occur later in each of the cylinders.

Many engines have a *stationary pointer* located above the *crankshaft pulley* (Figure 13-6). This stationary pointer has marks that refer to degrees of advance (before) or retard (after) for the No. 1 cylinder. A mark on the crankshaft pulley is used to determine the position of the No. 1 piston in relation to the stationary pointer. When the mark is lined up with the zero on the stationary pointer, the piston in cylinder No. 1 is at TDC (Figure 13-6).

Many front-wheel drive cars have a *window* cut in their bell housing (Figure 13-7) and timing marks on the *flywheel*. A *pointer* or *reference line* is positioned next to the window for the timing reference.

Basic timing is checked and adjusted to specificiations with a timing light or magnetic probe. (The use of the timing light and magnetic probe is discussed in Unit 14.) The distributor can be rotated when the engine is idling to set the correct basic timing for the No. 1 cylinder. When the correct basic timing is set for the No. 1 cylinder, ignition will occur in the other cylinders at the correct time.

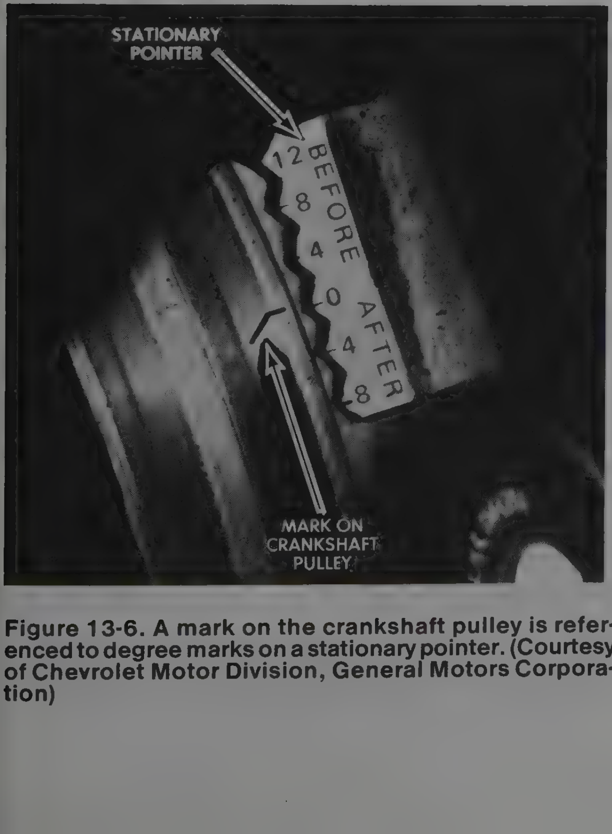


Figure 13-6. A mark on the crankshaft pulley is referenced to degree marks on a stationary pointer. (Courtesy of Chevrolet Motor Division, General Motors Corporation)

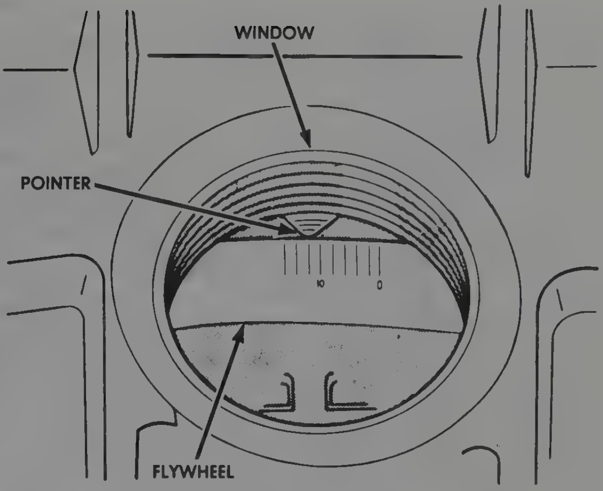


Figure 13-7. Timing on some front-wheel drive cars is achieved through a window on the bell housing. (Courtesy of Chrysler Corporation)

Speed Advance

Engine speed is an important influence on ignition timing. The higher the engine speed, the less time is available for the air-fuel mixture to ignite, burn, and produce power for the piston. For the maximum power to be produced at higher engine speeds, the ignition system must deliver the high-voltage surge to the cylinder earlier in the cycle than it does at lower engine speeds.

Assume that the burning time (process) of a given air-fuel mixture is .003 of a second. To obtain full power from combustion with the spark occurring 8° BTDC, maximum pressure will be reached while the piston is 10° ATDC (Figure 13-8). At 1,000 RPM, the engine's crankshaft travels through 18° in .003 of a second. At 2,000 RPM, the crankshaft travels through 36°. Since the maximum pressure point is fixed, the spark must be delivered into the cylinder earlier in the cycle in order to deliver full power as engine speed increases.

A common method of sensing and adjusting ignition timing to engine speed is a **centrifugal**

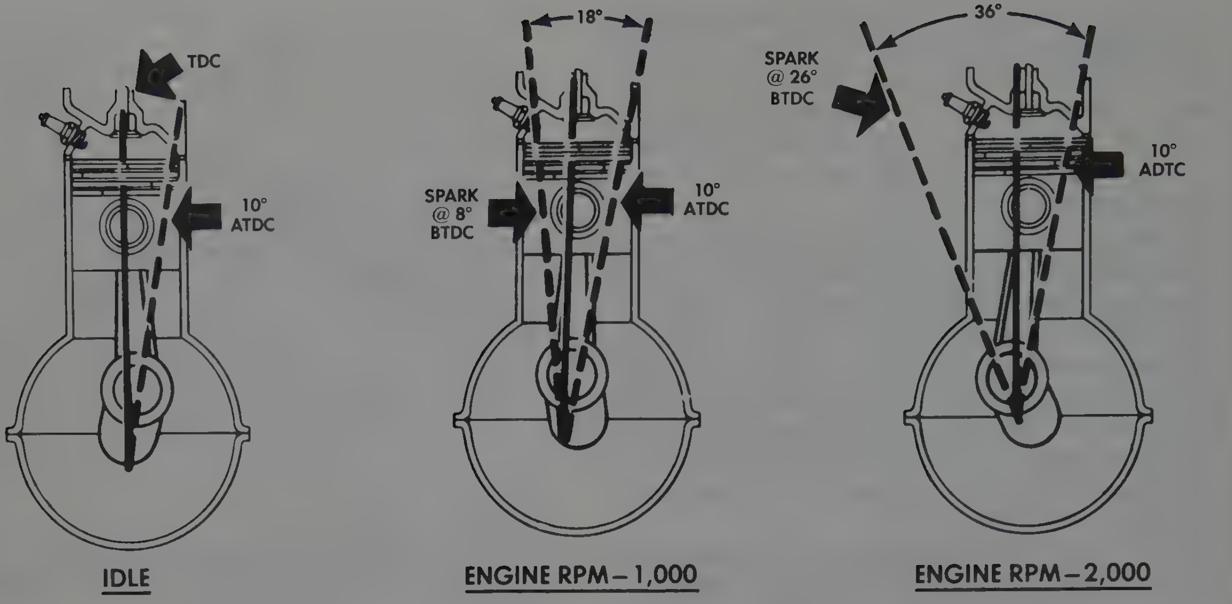

TDC
10° ATDC
IDLE
18°
SPARK @ 8° BTDC
10° ATDC
ENGINE RPM – 1,000
36°
SPARK @ 26° BTDC
10° ADTC
ENGINE RPM – 2,000

Figure 13-8. To obtain maximum power at higher engine speed, ignition must occur earlier in the cycle. (Courtesy of Chevrolet Motor Division, General Motors Corporation)

advance mechanism (Figure 13-9). This mechanism consists of a set of *spring-loaded centrifugal weights* mounted on the distributor *shaft*. The centrifugal weights are used to connect the shaft and breaker cam (or reluctor). The centrifugal weights push out against the spring's tension as engine speed increases. This motion turns the breaker cam (or reluctor) so that it rotates in the direction of shaft rotation.

The two extreme positions of a typical centrifugal advance mechanism are shown in Figure 13-10: at *idle (no advance)* and at *high speed (full advance)*. The amount of advance is controlled by the *calibrated springs* and the design of the *cam contour* of the *centrifugal weights*, which moves the cam plate attached to the *breaker cam* (or reluctor). By dynamometer tests at wide-open throttle, the factory determines the correct timing point required to reach peak power at each speed throughout the entire engine speed range. The centrifugal advance mechanism is then designed to automatically follow this series of timing points.

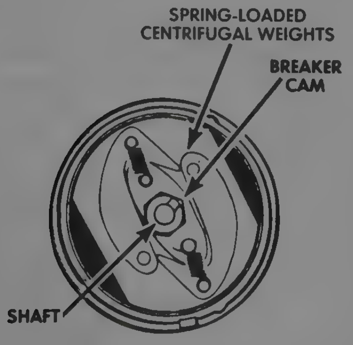

SPRING-LOADED CENTRIFUGAL WEIGHTS
BREAKER CAM
SHAFT

Figure 13-9. A centrifugal advance mechanism is used to sense and adjust ignition timing to engine speed. (Courtesy of Chevrolet Motor Division, General Motors Corporation)

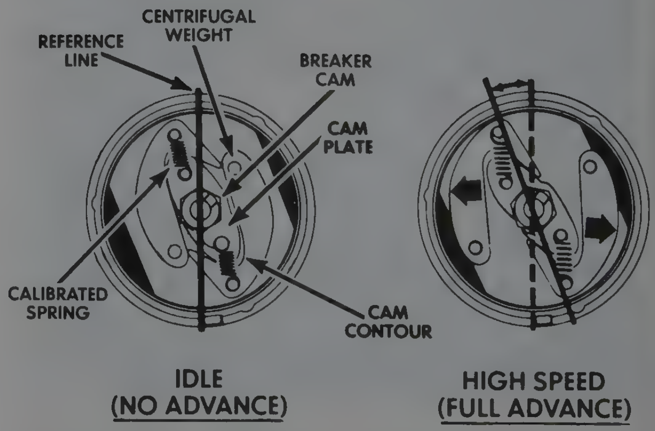

REFERENCE LINE
CENTRIFUGAL WEIGHT
BREAKER CAM
CAM PLATE
CALIBRATED SPRING
CAM CONTOUR
IDLE (NO ADVANCE)
HIGH SPEED (FULL ADVANCE)

Figure 13-10. Position of the centrifugal advance mechanism at idle and at full advance. (Courtesy of Chevrolet Motor Division, General Motors Corporation)

If these timing points were plotted on a graph, straight lines would be produced in some cases. In others, because the spark advance does not increase proportionally with engine speed increase, the curve would break or "dog-leg" at some intermediate speeds (Figure 13-11). Maximum advance provided for some engines is only a few crankshaft degrees. Other engines can use as much as 50 or more crankshaft degrees advance at high speed.

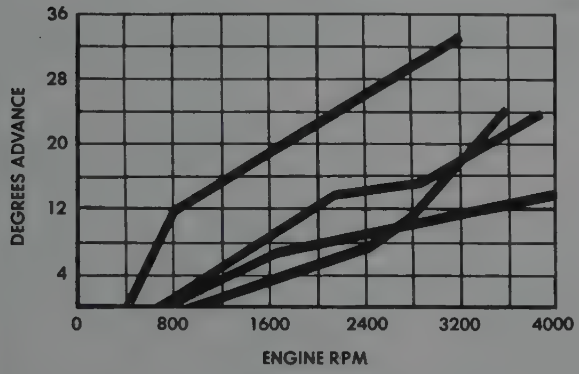


Figure 13-11. Graph showing typical centrifugal advance curves for different engines. (Courtesy of Delco Remy, Division of General Motors Corporation)

Load Advance

When an engine is operating under a light load, with throttle partially open, the combustion process is slower. Because the air-fuel mixture under these conditions is less tightly compressed, the combustion process requires more time and an additional spark advance for maximum power and economy. Since engine manifold vacuum varies with engine load, vacuum is used to provide an additional amount of advance and is called *vacuum advance*.

The breaker points or pickup unit is mounted on a *breaker plate* in the distributor. There is a *bearing* between the breaker plate and the distributor housing which allows the breaker plate to move back and forth. A **vacuum advance mechanism** is mounted on the side of the distributor (Figure 13-12). It consists of a *diaphragm housing*, a *spring*, a *diaphragm*, and an air-tight, spring-loaded *diaphragm linkage* which connects with the breaker plate.

The spring-loaded, air-tight side of the diaphragm is connected by a *vacuum line* to a *vacuum passage opening* in the *carburetor*. This opening is on the atmospheric side, or low-pressure side, of the *throttle valve* when the throttle is in the idle position so that there will be no vacuum advance. However, when the throttle valve is opened, it swings past the vacuum passage opening. The manifold vacuum can now work through this vacuum passage opening on the diaphragm, causing the spring to compress and the breaker plate to rotate.

The rotation moves the pickup unit or breaker points in a direction so that the reluctor signals the electronic control unit, or the breaker cam closes and opens the breaker points earlier in

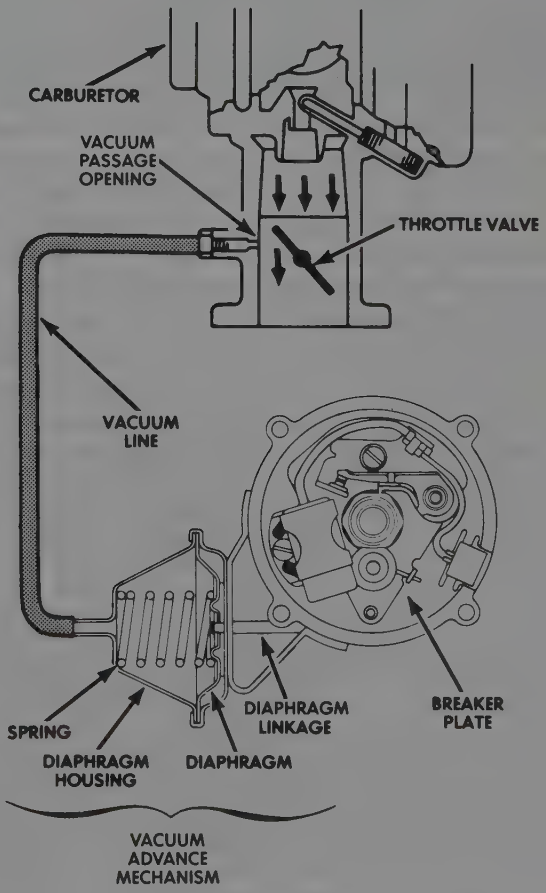


Figure 13-12. The vacuum advance mechanism moves the breaker plate for vacuum advance. (Courtesy of Chevrolet Motor Division, General Motors Corporation)

the compression stroke (Figure 13-13). This provides the desired vacuum advance. The amount of throttle valve opening determines, in part, the amount of intake manifold vacuum and thus the amount of load spark advance.

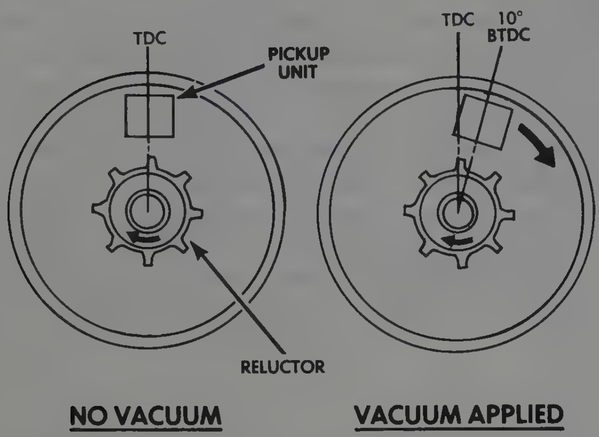


Figure 13-13. The vacuum advance mechanism moves the pickup unit in relation to the reluctor.

Any engine speed will cause a certain amount of centrifugal advance. Additional advance may result from vacuum conditions in the intake manifold. A typical centrifugal-vacuum advance curve is shown in Figure 13-14. The *centrifugal advance* will supply 15° advance at *40 MPH*, whereas the *vacuum advance* will produce up to 15° additional advance under partial throttle operation. However, with wide-open throttle, there will be little vacuum in the intake manifold. Consequently, little vacuum advance will be obtained. In actual operation, the total advance achieved will be somewhere between the centrifugal advance curve and the total advance possible on the graph. Partial throttle operation permits the vacuum advance mechanism to function so that greater economy is achieved than with wide-open throttle.

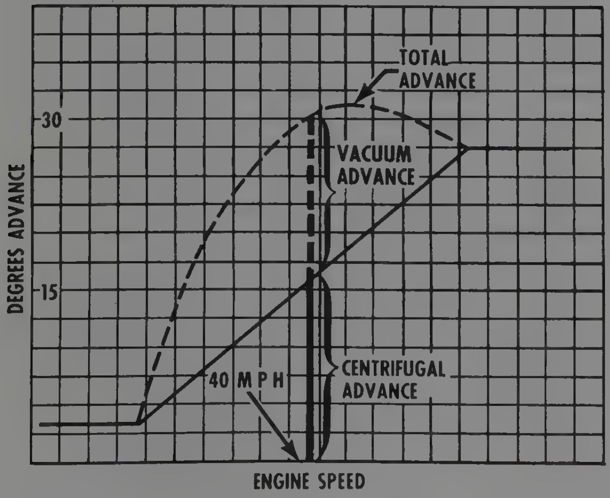


Figure 13-14. Typical centrifugal-vacuum advance curve plotted on a graph. (Courtesy of Delco Remy, Division of General Motors Corporation)

Some distributors use only centrifugal advance and do not have a vacuum advance mechanism. Others are equipped with one or more vacuum diaphragms to provide the complete advance and do not use a centrifugal advance mechanism.

COMPUTER-CONTROLLED TIMING

Advances in electrical microprocessor technology have been applied to ignition timing. A **microprocessor** is an analog or digital information processor which uses integrated circuits manufactured by spraying conducting materials onto a silicon chip.

Ignition timing is important not only in developing engine power, but also in increasing fuel mileage and reducing emissions. On-board microprocessor computers (Figure 13-15) make it possible to sense and adjust timing in relation to many more variables than just engine speed and load.

A simplified diagram of an electronic spark timing system using a microprocessor is

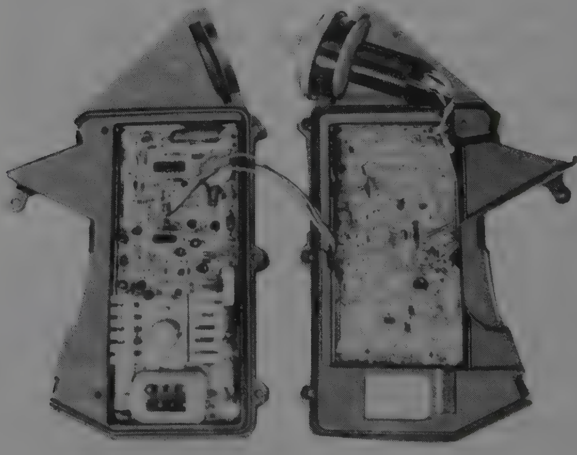


Figure 13-15. On-board microprocessor computers can be used to regulate ignition timing. (Courtesy of Chrysler Corporation)

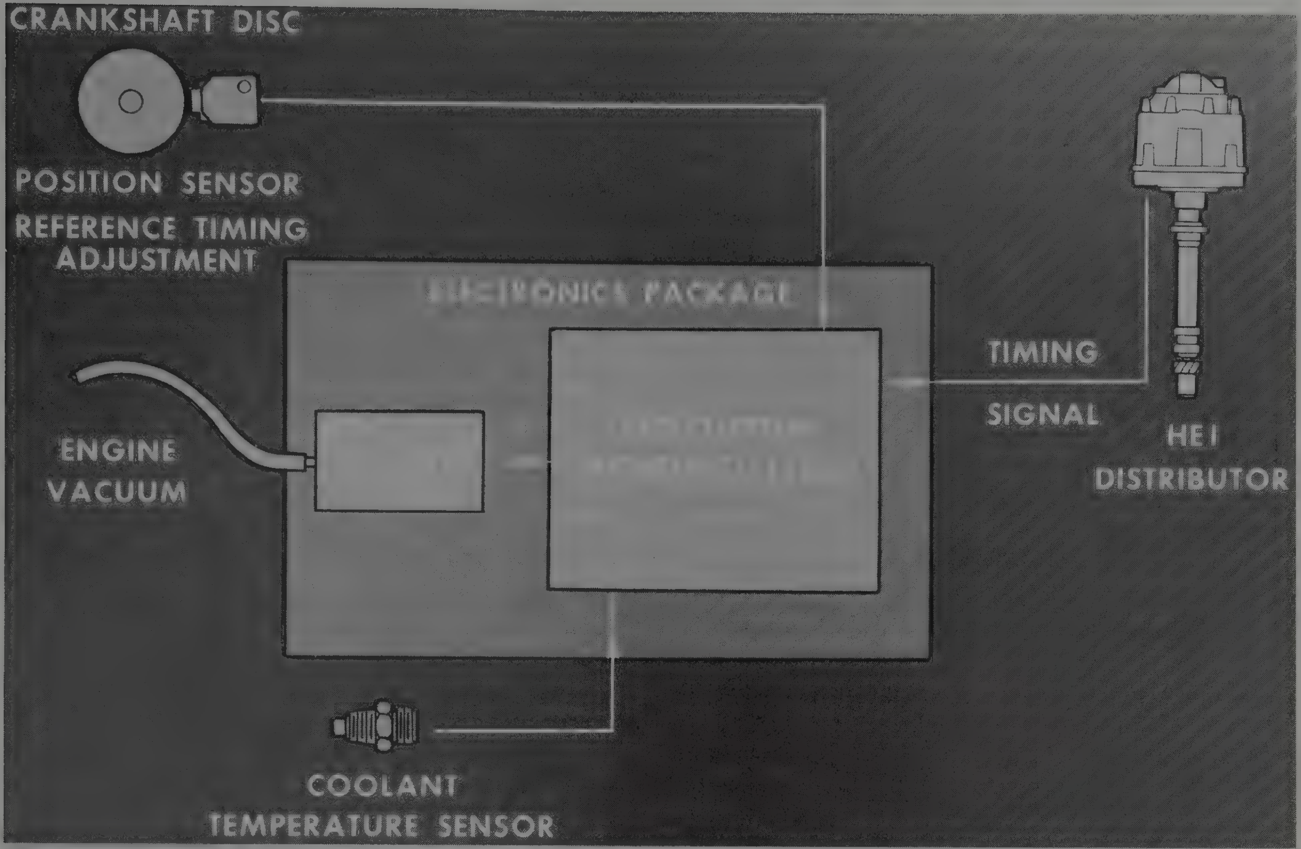


Figure 13-16. Simplified diagram of an electronic spark timing system using a microprocessor. (Courtesy of Oldsmobile Division, General Motors Corporation)

shown in Figure 13-16. The position of the crankshaft is sensed by a *position sensor* mounted over the crankshaft. A *crankshaft disc* on the crankshaft is used to influence the position sensor. A *coolant temperature sensor* provides the microprocessor with temperature information. An *engine vacuum sensor* provides the computer with an indication of engine load. All this information is directed to the HEI distributor as a *timing signal* which adjusts the ignition timing.

The distributor used with most microprocessor-controlled timing systems has no vacuum or centrifugal advance mechanisms. The only purpose of the primary circuit in this type of distributor is to let the microprocessor know the crankshaft position. The microprocessor can then electronically adjust the time when the ignition coil primary circuit is broken to develop secondary current. Microprocessor-controlled timing can consider an unlimited number of variables and change all three types of timing (basic, speed, and load) to meet specific operating conditions.

Most late-model timing systems include an air-fuel mixture feedback system from the exhaust pipe. This system is discussed in the units on the fuel system and emission control system.

DUAL POINT AND DUAL PICKUP DISTRIBUTORS

The purpose of dual point and dual pickup distributors is to provide either advanced or retarded basic timing during specific operating modes such as engine warm-up, full throttle operation, or other special conditions.

The ignition coil produces a high-voltage spark when its ground circuit is broken by the breaker points opening. The moment at which the breaker points open is controlled by the position of the breaker points in relation to the cam lobes on the breaker cam. This position determines the basic timing and can be changed by loosening the hold-down bolt and rotating the distributor.

Suppose that we want to advance the timing only when the engine is cold to ensure smoother running during warm-up. One way to do this is to rotate the distributor a few degrees. However, this would change the amount of advance throughout the entire operating range. Instead of rotating the distributor a few degrees, a second set of breaker points (*retard breaker points*) can be installed almost directly across from the first set of breaker points (*advance breaker points*) (Figure 13-17). If the advance breaker points are placed exactly opposite the retard breaker points, the two sets will open and close at exactly the same time. However, if the advance breaker points are just a few degrees away from being directly opposite, then the two sets will open at slightly different times.

The advance breaker points are used during warm-up, and the ignition system is switched (by a relay) to the retard breaker points after the engine reaches operating temperature. The two breaker point sets are wired so that they can both work at the same time, and the relay is used to control the advance set.

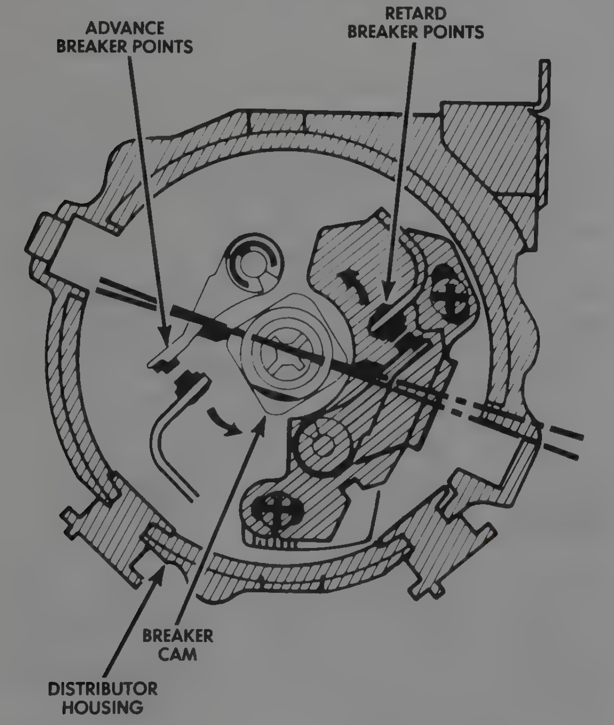


Figure 13-17. A dual breaker point distributor has a set of advance breaker points and a set of retard breaker points. (Courtesy of Nissan Motor Corporation in U.S.A.)

The difference between the breaker point open positions of the dual point distributor is the **phase difference**. It is expressed as the number of degrees through which the distributor cam must rotate once the retard set has opened to the point when the advance set opens. A phase difference of 5° gives an ignition timing change of 10°. This is because the distributor is turning only half as fast as the crankshaft. A 5° movement of the distributor breaker cam results in 10° movement of the crankshaft (Figure 13-18).

The control relay windings receive current when the ignition switch is in the ON or START position. When the windings are grounded, the relay closes and supplies current to the retard breaker points. The control relay is connected to a number of sensors such as ambient air temperature, coolant temperature, throttle position, gear detector, and clutch position. Only when the sensor switches are in the correct position will the control relay have a ground and close, activating the retard points.

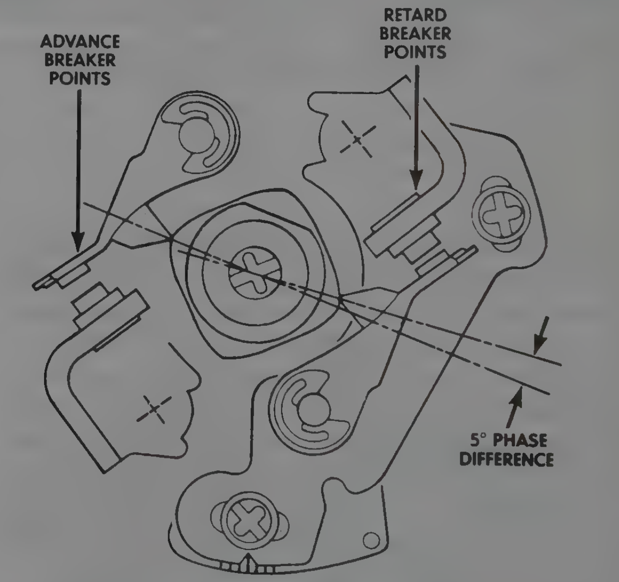


Figure 13-18. The retard breaker points are out of phase with the advanced breaker points, creating a phase difference. (Courtesy of Nissan Corporation in U.S.A.)

A similar system is used for vehicles with electronic ignition distributors. An electronic ignition distributor may be equipped with pickup units (Figure 13-19). The pickup units are out of phase just as the dual breaker points would be out of phase. One pickup unit is in an advanced position and the other in a retard position.

A control relay and sensor system is used to switch to the retard pickup unit. However, unlike the dual breaker point system, only one pickup unit functions at a time. When the sensor switches activate the control relay, the transistor ignition control unit automatically switches from one pickup unit to the other. Engine performance is not affected during the change, since the transistorized ignition control unit is much faster and more reliable than a mechanical switch.

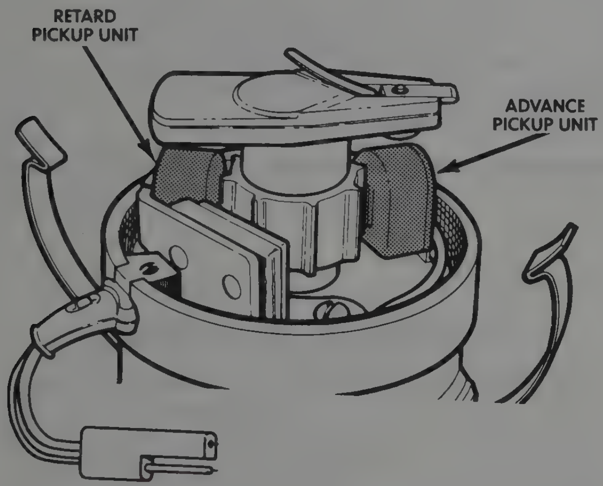


Figure 13-19. An electronic ignition distributor with two pickup units. (Courtesy of Chrysler Corporation)

KEY TERMS

Basic timing: Timing established by the position of the distributor in the engine.

Centrifugal advance mechanism: An ignition timing component sensitive to engine speed and used to advance ignition spark.

Combustion: The controlled burning process of the air-fuel mixture in the engine's combustion chamber.

Microprocessor: An information processor that changes ignition timing based on variables of engine speed and load.

Phase difference: An angle, expressed in degrees, between the advance and the retard action of a dual point or dual pickup distributor.

Vacuum advance mechanism: An ignition timing component sensitive to engine load, which uses engine vacuum to the distributor to advance the ignition spark.

SELF-CHECK

1. What do the letters BTDC and ATDC stand for?
2. List the factors that affect combustion time.
3. What is basic timing?
4. How is basic timing changed?
5. What is the purpose of the centrifugal advance mechanism?
6. List the main parts of the centrifugal advance mechanism.
7. What is the purpose of the vacuum advance mechanism?
8. List the main parts of the vacuum advance mechanism.
9. How is the total advance at any vehicle speed determined?
10. What is the advantage of a computer-controlled timing system?
11. What are the two sets of breaker points in a dual point distributor called?
12. Why are the breaker points in a dual point distributor out of phase?
13. What is used to switch from one pickup unit to another in a dual pickup distributor?

DISCUSSION TOPICS AND ACTIVITIES

1. Look up the advance curve specifications for a distributor. How can the advance curve be changed?
2. Connect a timing light to a test engine. How can basic, centrifugal, and vacuum timing be obtained?

CERTIFICATION PRACTICE

1. The time required for combustion is affected by:
   A. Combustion chamber shape
   B. Spark plug position
   C. Air-fuel mixture
   D. All of the above
2. The time required for combustion is longer:
   A. When the vehicle is under a heavy load
   B. When the vehicle is under a light load
   C. When the engine is hot
   D. None of the above
3. Ignition is determined by:
   A. Basic timing
   B. Centrifugal advance
   C. Vacuum advance
   D. All of the above
4. The timing of ignition to engine speed is accomplished with:
   A. Basic timing
   B. Centrifugal advance
   C. Vacuum advance
   D. None of the above
5. The timing of ignition to engine load is accomplished with:
   A. Basic timing
   B. Centrifugal advance
   C. Vacuum advance
   D. None of the above

ANSWERS

1: D, 2: B, 3: D, 4: B, 5: C

Unit 14

TROUBLESHOOTING THE IGNITION SYSTEM

The purpose of a tune-up is to restore engine power, fuel economy, and emission levels to manufacturer's specifications. A problem in the ignition system can affect all of these areas. The tune-up technician can follow a logical step-by-step procedure to determine the existence of such a problem and to correct it. Specific troubleshooting procedures are provided in service manuals for particular vehicles. This unit presents general procedures that are useful for most ignition systems.

DEVELOPING JOB COMPETENCIES

When you finish reading and studying this unit, you should be able to:

- Perform a visual inspection on a vehicle with an ignition problem.
- Test the ignition secondary circuit on a vehicle, using basic instruments.
- Test the ignition primary circuit on a vehicle, using basic instruments.
- Check and adjust the vehicle's timing with a timing light.
- Check the ignition system for an abnormal firing section display pattern, intermediate section display pattern, and dwell section display pattern, using an oscilloscope.

IGNITION SYSTEM PROBLEMS

Faulty operation of an ignition system component can be the cause, or a contributing factor to the cause, of the following problems:

- An engine that cranks normally but will not start.
- An engine that starts but fails to continue to run.
- An engine that stalls when the vehicle is driven after stopping.
- An engine that does not idle properly.
- An engine with poor acceleration and poor fuel mileage.
- An engine that experiences power loss.
- An engine that misfires and has unacceptable emission levels.

A typical ignition system troubleshooting chart is shown in Figure 14-1. It lists some of the possible causes and corrective actions for each of these problems.

VISUAL CHECKS

When an ignition system problem is suspected, the tune-up technician should begin with a visual inspection. A quick look at each of the ignition system components may reveal an obvious problem such as a broken or disconnected wire. If no obvious problem is seen, the technician should begin a more systematic visual inspection.

The systematic visual inspection begins by checking **spark intensity** — the quality, or strength, of the spark produced at the spark plug. Spark intensity is checked with a *spark tester* (Figure 14-2). Remove a spark plug cable from one of the spark plugs. To avoid damaging the spark plug cable, remove it from the spark plug by grasping the boot and twisting it a

IGNITION SYSTEM TROUBLESHOOTING CHART

PROBLEM	POSSIBLE CAUSE(S)	CORRECTIVE ACTION(S)
ENGINE CRANKS NORMALLY BUT WILL NOT START	1. LOW SPARK INTENSITY 2. PRIMARY CIRCUIT: OPEN CIRCUIT IN PRIMARY WIRE DEFECTIVE IGNITION BYPASS CIRCUIT DEFECTIVE CONDENSER REVERSED IGNITION COIL POLARITY DEFECTIVE IGNITION COIL IMPROPER DWELL EXCESSIVE RESISTANCE DEFECTIVE PICKUP UNIT DEFECTIVE CONTROL UNIT 3. SECONDARY CIRCUIT: DEFECTIVE DISTRIBUTOR CAP DEFECTIVE ROTOR DEFECTIVE SECONDARY WIRING	REPLACE OR ADJUST COMPONENTS AS NECESSARY
ENGINE STARTS BUT FAILS TO KEEP RUNNING	DEFECTIVE PRIMARY RESISTANCE WIRE (OR BALLAST RESISTOR)	REPLACE RESISTOR
ENGINE STALLS WHEN DRIVING AWAY FROM A STOP	INTERNAL GROUND IN PRIMARY CIRCUIT	REPAIR GROUND
ENGINE DOES NOT IDLE PROPERLY	IMPROPER DWELL AND SPARK PLUG GAP	SET DWELL AND REPLACE SPARK PLUGS
	1. INCORRECT IGNITION TIMING 2. INCORRECT DISTRIBUTOR VACUUM ADVANCE MECHANISM OPERATION 3. DEFECTIVE DISTRIBUTOR BREAKER POINTS 4. LOW SPARK INTENSITY 5. WORN SPARK PLUGS	REPLACE OR ADJUST PARTS AS NECESSARY
POWER LOSS	1. INCORRECT IGNITION TIMING 2. WORN SPARK PLUGS 3. RESISTANCE OR LEAKS IN SECONDARY CIRCUIT	REPLACE OR ADJUST PARTS AS NECESSARY
MISFIRING/UNACCEPTABLE EMISSION LEVELS	IMLPROPER DISTRIBUTOR OPERATION 2. WORN SPARK PLUGS 3. EXCESSIVE RESISTANCE OR LEAKAGE IN SECONDARY CIRCUIT 4. IMPROPER WIRE ROUTING IN SECONDARY CIRCUIT	REPLACE OR ADJUST PARTS AS NECESSARY

Figure 14-1. Typical ignition system troubleshooting chart.

quarter-turn before pulling it off (Figure 14-3). **CAUTION: Do not pull the spark plug cable itself, but pull the boot of the cable.**

Install the spark plug cable on the end of the spark tester. Attach the tester clip to a good ground. Have an assistant crank the engine. Watch for a spark at the other end of the spark tester. **CAUTION: Do not touch the spark tester or cable during cranking, or you may get a shock from the high voltage.**

Watch for a spark at the end of the spark tester. A good spark is blue in color and can jump an air gap of at least 3/16" to ground. A weak spark or no spark definitely indicates a problem in the ignition system.

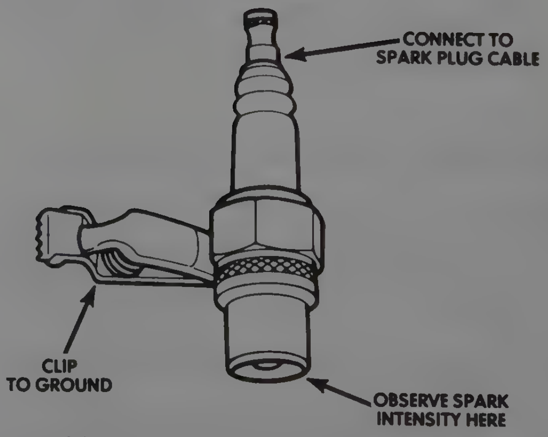


Figure 14-2. A spark tester is connected to a spark plug cable to check intensity. (Courtesy of Ford Motor Company)

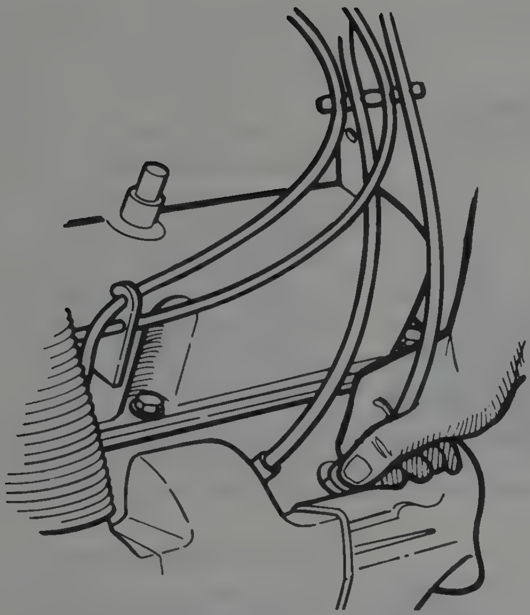


Figure 14-3. Remove a spark plug cable by pulling on the boot, not the cable itself. (Courtesy of Ford Motor Company)

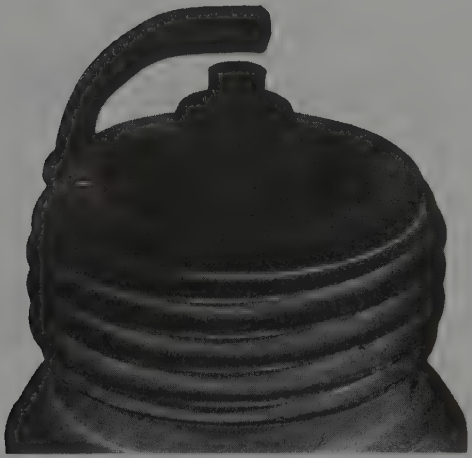


Figure 14-4. A wet or sooty electrode area on a spark plug may indicate an air-fuel mixture that is too rich.

If no spark is observed, recheck for a spark using another spark plug cable. If there is still no spark, remove the ignition coil secondary cable from the center distributor tower. Hold the cable with insulated pliers approximately 3/16" away from a good ground. Have your assistant crank the engine while you watch for a spark between the cable and ground. If there is a spark, the ignition secondary circuit is at fault.

If there is a weak spark or no spark at the end of the spark tester, and there is no spark at the ignition coil secondary wire, the ignition primary circuit may be at fault.

If the spark at the end of the spark tester is strong, the trouble may involve the spark plug, the fuel system, or engine compression. First, eliminate the spark plug as a possible cause of trouble. Remove one of the engine's spark plugs, and visually inspect the electrode area. If the electrode area is excessively wet, there is an excessive supply of fuel, indicating an air-fuel mixture that is too rich (Figure 14-4). Excessive wetness can also indicate a defective spark plug. Dryness, on the other hand, indicates an air-fuel mixture that is too lean (Figure 14-5). A spark plug analysis chart (Figure 14-6) may be used to further diagnose problems from the appearance of the spark plugs.

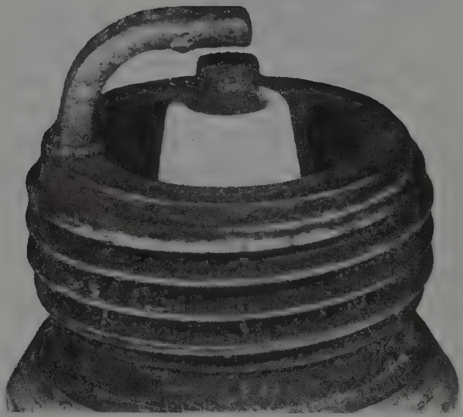
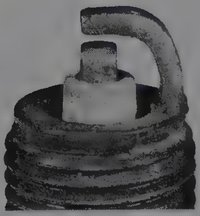


Figure 14-5. A dry electrode area on a spark plug may indicate an air-fuel mixture that is too lean.

A fouled or improperly gapped spark plug will not ignite the air-fuel mixture in the combustion chamber or will, at best, produce inadequate ignition. Too wide an air gap can produce a cross-firing condition between spark plug cables.

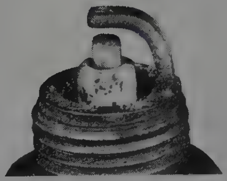
SPARK PLUG ANALYSIS CHART



NORMAL

Brown to grayish tan color and slight electrode wear. Correct heat range for engine and operating conditions.

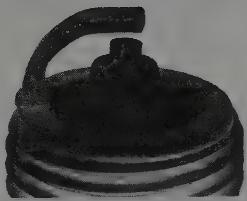
RECOMMENDATION. Properly service and reinstall. Replace if over 10,000 miles of service.



SPLASHED DEPOSITS

Spotted deposits. Occurs shortly after long delayed tune-up. After a long period of misfiring, deposits may be loosened when normal combustion temperatures are restored by tune-up. During a high-speed run, these materials shed off the piston and head and are thrown against the hot insulator.

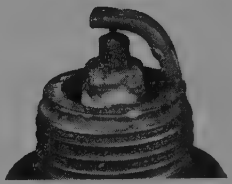
RECOMMENDATION. Clean and service the plugs properly and reinstall.



CARBON DEPOSITS

Dry soot.

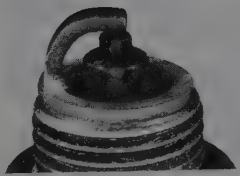
RECOMMENDATION. Dry deposits indicate rich mixture or weak ignition. Check for clogged air cleaner, high float level, sticky choke or worn breaker contacts. Hotter plugs will temporarily provide additional fouling protection.



HIGH SPEED GLAZING

Insulator has yellowish, varnish-like color. Indicates combustion chamber temperatures have risen during hard, fast acceleration. Normal deposits do not get a chance to blow off, instead they melt to form a conductive coating.

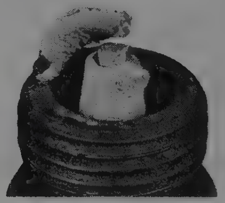
RECOMMENDATION. If condition recurs, use plug type one step colder.



OIL DEPOSITS

Oily coating.

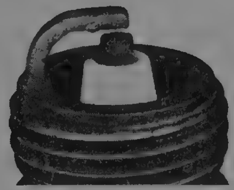
RECOMMENDATION. Caused by poor oil control. Oil is leaking past worn valve guides or piston rings into the combustion chamber. Hotter spark plug may temporarily relieve problem, but positive cure is to correct the condition with necessary repairs.



ASH DEPOSITS

Light brown to white colored deposits encrusted on the side or center electrodes or both. Derived from oil and/or fuel additives. While non-conductive, excessive amounts may mask the spark, causing misfire.

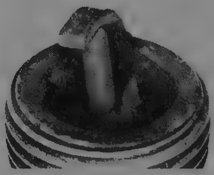
RECOMMENDATION. If excessive deposits accumulate in short mileage, corrective measures may include installation of valve guide seals to prevent seepage of oil into combustion chamber.



TOO HOT

Blistered, white insulator, eroded electrodes and absence of deposits.

RECOMMENDATION. Check for correct plug heat range, overadvanced ignition timing, cooling system level and/or stoppages, lean fuel/air mixtures, leaking intake manifold, sticking valves, and if car is driven at high speeds most of the time.



MECHANICAL DAMAGE

Mechanical Damage to the plug's firing end is caused by some foreign object in the combustion chamber. It may also be due to the piston striking the firing tip of improper reach plugs. When working on an engine, be sure to keep the carburetor throat and any open plug holes covered. Consult the catalog for proper reach plugs.

Figure 14-6. Spark plug analysis chart.

TESTING THE IGNITION SYSTEM WITH BASIC INSTRUMENTS

When it has been determined that there is a problem in the ignition system, the tune-up technician must follow a step-by-step procedure to isolate the problem. Each car manufacturer has its own ignition tester (Figure 14-7) and procedure for testing the ignition systems in its vehicles. If this tester and procedure are available, they should be used. If not, an oscilloscope (discussed later in this unit) can be used to isolate ignition problems. If a manufacturer's ignition tester or oscilloscope is not available, other basic instruments or equipment can be used to isolate the problem.

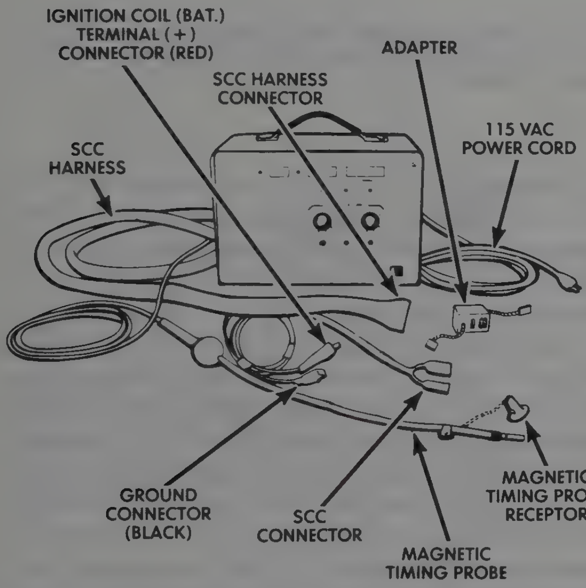

IGNITION COIL (BAT.) TERMINAL (+) CONNECTOR (RED)
ADAPTER
SCC HARNESS CONNECTOR
115 VAC POWER CORD
SCC HARNESS
GROUND CONNECTOR (BLACK)
SCC CONNECTOR
MAGNETIC TIMING PROBE RECEPTOR
MAGNETIC TIMING PROBE

Figure 14-7. Each manufacturer provides its own ignition tester for its vehicles. (Courtesy of Chrysler Corporation)

Testing the Secondary Circuit

If no spark is observed at the end of a spark tester, but a good spark is produced from the ignition coil secondary wire or cable, the problem exists in the secondary circuit. Trouble in the secondary circuit can usually be traced to the distributor cap, rotor, or spark plug cables.

The most common cause of trouble in the secondary circuit is a broken or cracked distributor cap (Figure 14-8), or corroded terminals or carbon build-up that provide a path for current flow (Figure 14-9). If these conditions exist, a missing, or misfiring, condition can develop. A visual inspection is usually an effective check. (Oscilloscope patterns, however, are a more reliable means of determining whether or not a distributor cap is defective.)

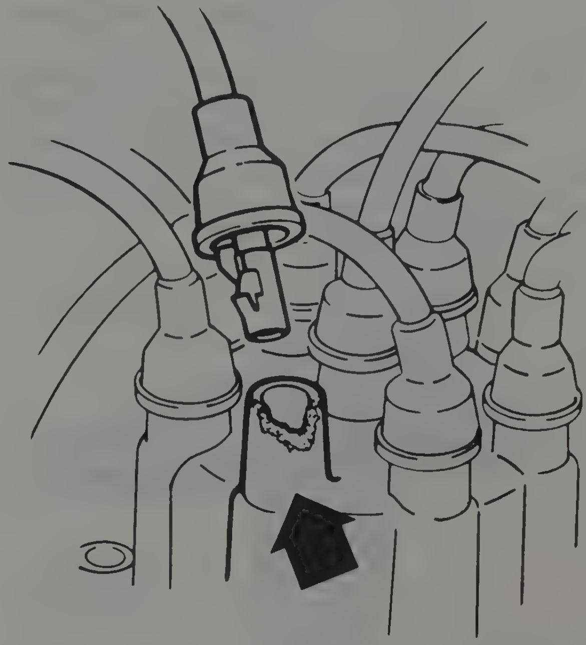


Figure 14-8. A broken or cracked distributor cap (see arrow) results in misfiring. (Courtesy of Delco Remy, Division of General Motors Corporation)

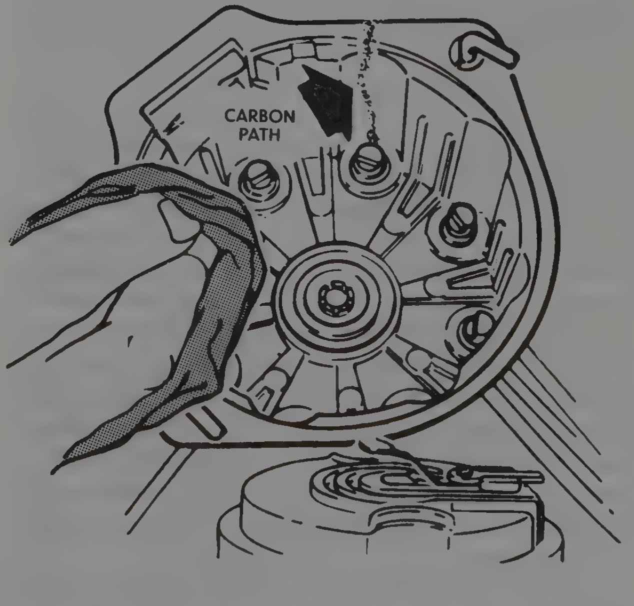

CARBON PATH

Figure 14-9. Carbon build-up inside the distributor cap may provide a path for current flow and result in misfiring. (Courtesy of Delco Remy, Division of General Motors Corporation)

A rotor can break, become pitted or burned, become corroded, or develop a loose fit on top of the distributor shaft. In most cases, a visual inspection is adequate to locate the cause of trouble (Figure 14-10). To detect a loose rotor, manually check the tightness of its fit on the shaft. (Again, oscilloscope patterns will show defective rotors.)

Inspect the boots and insulation of spark plug cables. Repeated heating and cooling, combined with extreme moisture and oil exposure, causes the insulation to deteriorate rapidly. If the boot or cable is excessively spongy or brittle, it should be replaced.

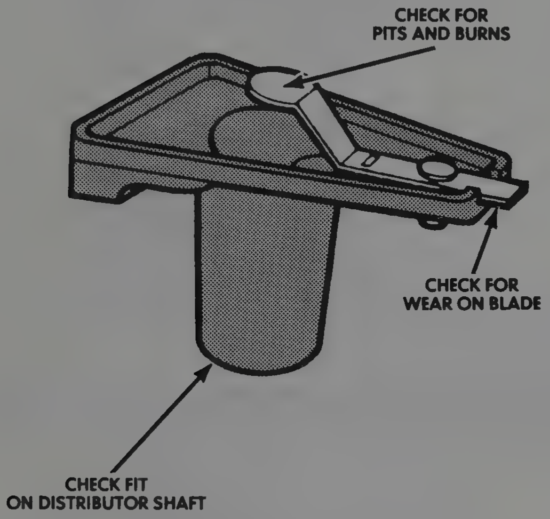


Figure 14-10. Visual inspection of the rotor may reveal the cause of misfiring. (Courtesy of Ford Motor Company)

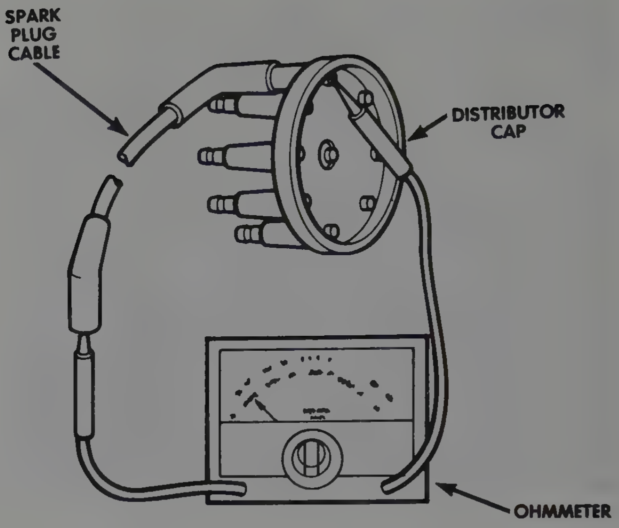


Figure 14-11. The resistance of the spark plug cables is measured with an ohmmeter. (Courtesy of Ford Motor Company)

One method of checking a spark plug cable electrically is to measure its resistance with an ohmmeter (Figure 14-11). Calibrate the ohmmeter to the zero line. Turn the range selector knob to the highest scale. Remove the distributor cap from the distributor. Disconnect one spark plug cable from a spark plug. Connect one ohmmeter test lead to the *spark plug cable* terminal and the other lead to the matching metal insert or terminal in the *distributor cap* as shown in Figure 14-11. Record the resistance. Repeat this procedure for each of the spark plug cables.

Check the readings obtained with the ohmmeter against specifications. Spark plug cable resistance specifications are usually given in ohms per foot (Ω /ft.). The longer the spark plug cable, the higher the resistance is. The length of the spark plug cable may have to be measured to determine if it meets specifications. Replace the spark plug cables if resistance is higher than specifications.

The secondary circuit in the ignition coil may also be checked for resistance with an ohmmeter (Figure 14-12). Remove the primary and secondary wires from the ignition coil. Calibrate the ohmmeter and turn the range selector knob to the highest scale. Connect one ohmmeter test lead to the negative (−) *primary terminal* and the other to the secondary terminal. Check the resistance reading against specifications. If the reading is higher than specifications, replace the ignition coil.

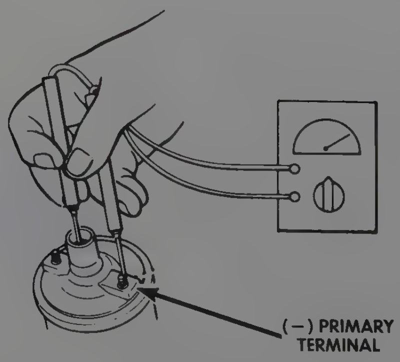


Figure 14-12. The resistance of the ignition coil secondary is measured with an ohmmeter. (Courtesy of Nissan Motor Corporation in U.S.A.)

Testing the Primary Circuit

If no spark or a weak spark is observed at the end of a spark tester, and there is also no spark at the ignition coil secondary wire, the primary circuit is probably at fault. First, make a visual inspection for an open circuit. An open circuit can be caused by loose locknuts, broken or grounded connections, overloaded circuits, or careless installations (Figure 14-13).

Resistance may also be checked by hooking a suitable voltmeter across a current-carrying circuit in the ignition coil. The voltage reading indicates the voltage drop and is an indication of resistance, as discussed in Unit 4.

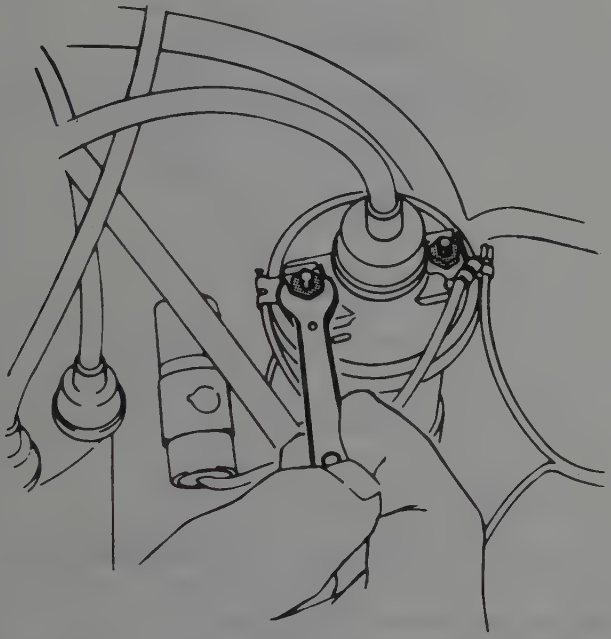


Figure 14-13. Tighten loose or disconnected primary wires to prevent an open circuit. (Courtesy of Delco Remy, Division of General Motors Corporation)

The only way the ignition coil polarity could be reversed would be through reversed (incorrect) installation of the two coil primary leads. Secondary voltage requirements could increase substantially under reversed polarity conditions. Since all coil primary terminals are marked positive (+) and negative (−), or BAT and DIST, make sure that the wire lead from the ignition or key switch is connected to the positive (+) or BAT terminal. The ignition coil to distributor lead should be connected to the negative (−) or DIST terminal (Figure 14-14).

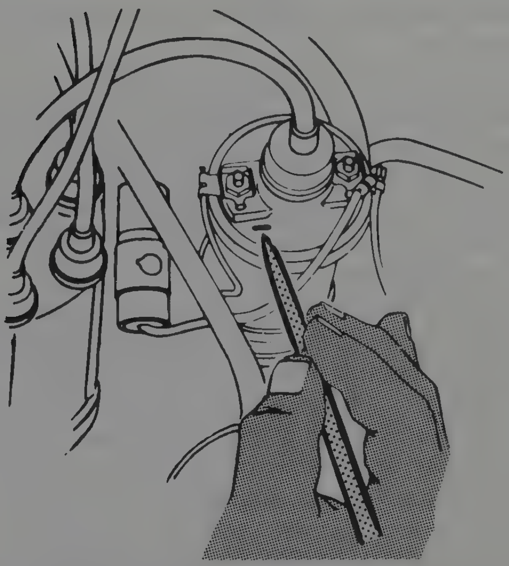


Figure 14-14. The negative (-) or DIST terminal of the ignition coil should be connected to the distributor. (Courtesy of Delco Remy, Division of General Motors Corporation)

The ignition coil primary circuit should be checked for excessive resistance with an ohmmeter (Figure 14-15). Disconnect the primary and secondary wires or leads from the ignition coil. Calibrate the ohmmeter. Connect a tester lead to each of the ignition coil primary terminals.

CAUTION: To protect the meter, start with the range selector knob on the highest scale, then switch to the lowest, as discussed in Unit 4.

Compare the resistance reading from the ohmmeter to specifications. If resistance is excessive, replace the ignition coil.

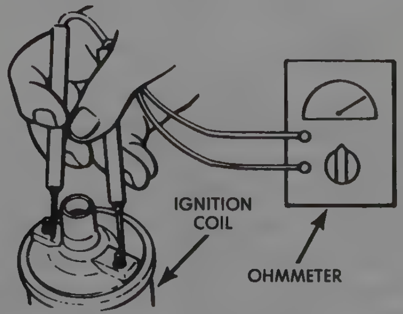


Figure 14-15. The resistance of the ignition coil primary circuit is measured with an ohmmeter. (Courtesy of Nissan Motor Corporation in U.S.A.)

Basic Testing of Electronic Ignition Systems

The components of an electronic ignition system must be tested to determine if they are faulty. Specific manufacturer's testers are available for this purpose. A discussion follows of test procedures that can be made with basic instruments on the most common types of electronic ignition systems.

Among the main components of an electronic ignition system are the reluctor, the pickup unit, and the electronic control unit. These three components are called different names by different vehicle manufacturers. The chart in Figure 14-16 compares the different names.

A problem in the electronic control unit or pickup unit usually results in a no-spark condition. The engine will crank but not start. The reluctor rarely causes a problem since it is a simple magnet. When testing any electronic ignition system, make sure the battery is fully charged. A low battery voltage can produce false test readings.

COMPARISON/IDENTIFICATION CHART

VEHICLE MANUFACTURER	MANUFACTURER'S NAME FOR		
	ELECTRONIC CONTROL UNIT	PICKUP UNIT	RELUCTOR
AMERICAN MOTORS CORPORATION	CONTROL UNIT	SENSOR ASSEMBLY	TRIGGER WHEEL
CHRYSLER CORPORATION	CONTROL UNIT	MAGNETIC PICKUP	RELUCTOR
FORD MOTOR COMPANY	MODULATOR ASSEMBLY	STATOR	ARMATURE
GENERAL MOTORS CORPORATION	MODULE	POLE PIECE	TIMING OR TIMER CORE

Figure 14-16. Chart comparing the names of components produced by different manufacturers.

American Motors Corporation. For basic testing of an electronic ignition system by American Motors Corporation (Figure 14-17), refer to the wiring diagram in Figure 14-18. This electronic ignition system is equipped with a *trigger wheel* (reluctor). Connect *voltmeter A* to the positive (+) terminal of *ignition coil* and *ground*. Turn the *ignition switch* on and observe the voltmeter. The reading should be about 12 volts. Have an assistant crank the engine and observe the voltmeter. The reading should be 10 to 11 volts. If the voltage is too low in either test, and if the charging and starting systems revealed no problem when tested, check the ignition switch and the *wiring* between the *battery* and the ignition coil.

Connect *voltmeter B* to positive (+) and negative (−) ignition coil terminals. Unplug the *sensor assembly* lead located outside the distributor, and turn the ignition switch on. The voltmeter reading should be 5 to 7 volts. If the reading is 12 to 13 volts, replace the *control unit*. If no voltage is observed, check the *ground*

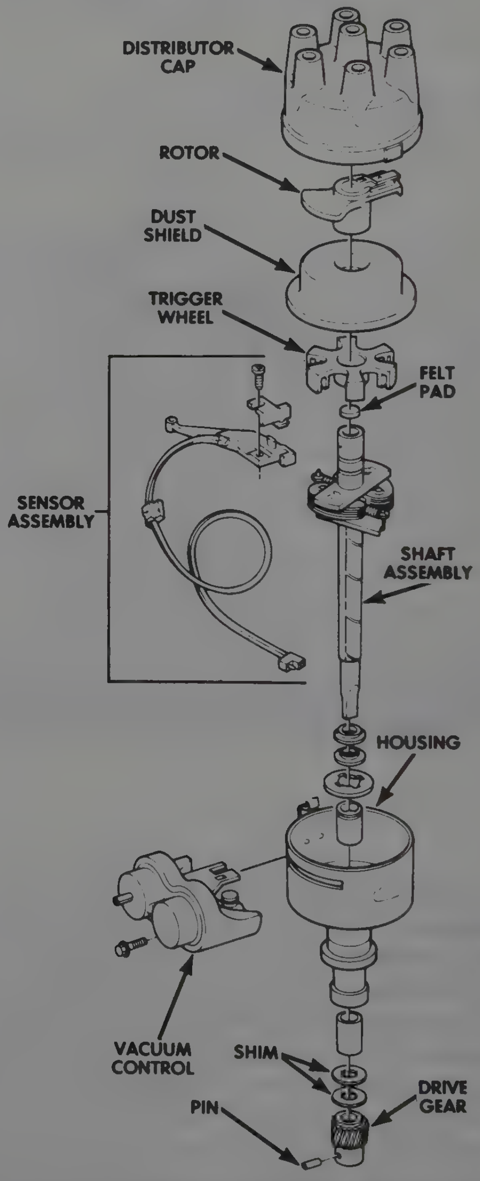


Figure 14-17. American Motors Corporation electronic ignition distributor nomenclature. (Courtesy of American Motors Corporation)

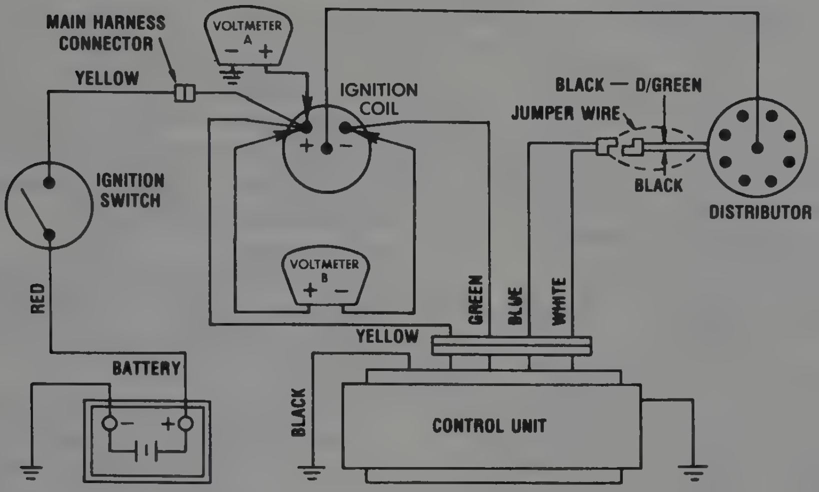

MAIN HARNESS CONNECTOR
VOLTMETER A
− +
YELLOW
IGNITION COIL
+ −
BLACK — D/GREEN
JUMPER WIRE
BLACK
DISTRIBUTOR
IGNITION SWITCH
VOLTMETER B
+ −
RED
GREEN
BLUE
WHITE
YELLOW
BATTERY
− +
BLACK
CONTROL UNIT

Figure 14-18. Voltmeter and jumper wire connections for testing an American Motors Corporation electronic ignition system. (Courtesy of C. E. Niehoff & Co.)

lead of the control unit. If no problem is revealed with the ground lead, replace the control unit.

With the voltmeter connected as just described, short across the lead terminals of the control unit side with a *jumper wire*. Turn the ignition switch on. No voltage should be indicated on the voltmeter. A reading of 5 to 6 volts indicates that the control unit should be replaced.

Next, with the ignition switch on, disconnect the high-voltage cable from the center of the distributor cap. Hold it with insulated pliers approximately 3/16" away from the ground. Check for a spark each time the lead terminals on the control unit side are shorted with a jumper wire. If a spark occurs, replace the sensor assembly. If no spark occurs, replace the ignition coil.

Chrysler Corporation. For basic testing of an electronic ignition system by Chrysler Corporation (Figure 14-19), refer to the wiring diagram

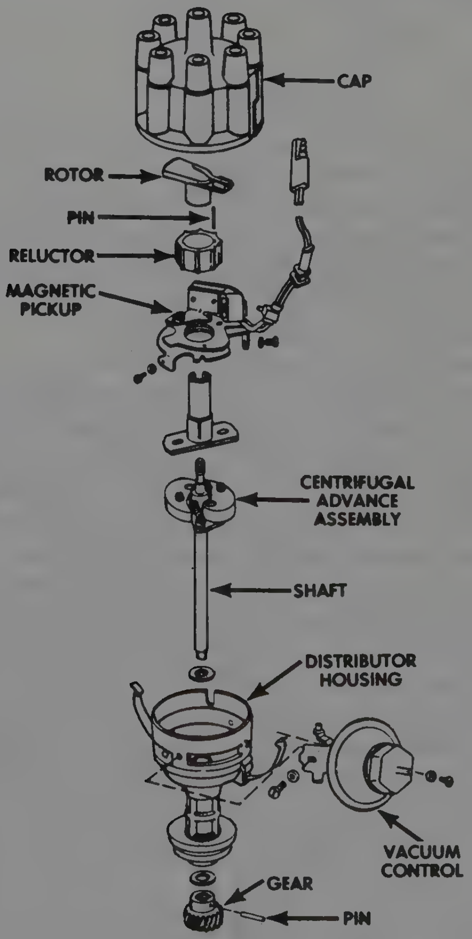

CAP
ROTOR
PIN
RELUCTOR
MAGNETIC PICKUP
CENTRIFUGAL ADVANCE ASSEMBLY
SHAFT
DISTRIBUTOR HOUSING
VACUUM CONTROL
GEAR
PIN

Figure 14-19. Chrysler Corporation electronic ignition distributor nomenclature. (Courtesy of Chrysler Corporation)

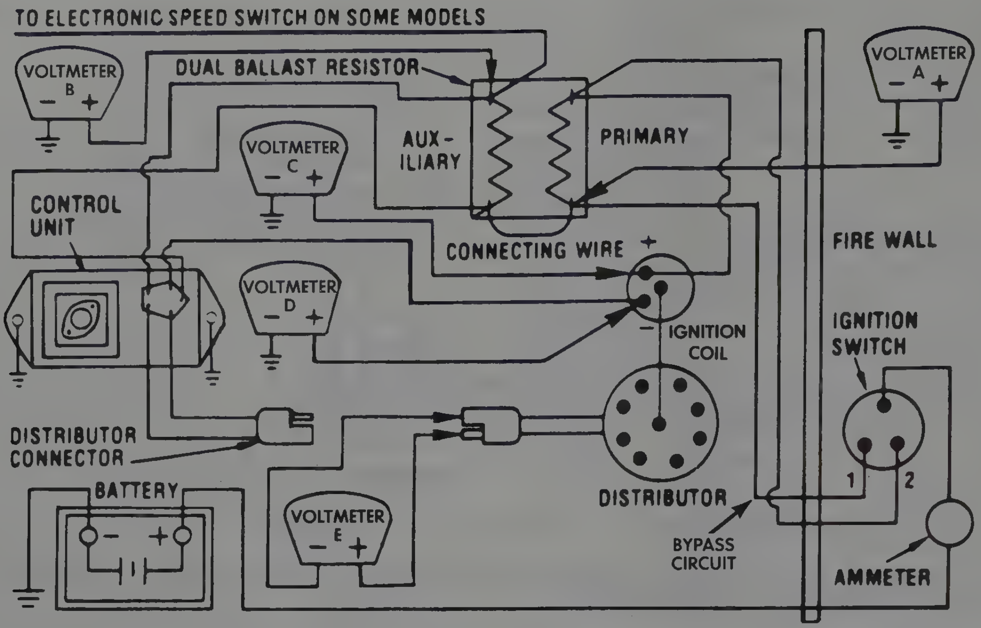


Figure 14-20. Voltmeter connections for testing a Chrysler Corporation electronic ignition system. (Courtesy of C.E. Niehoff & Co.)

in Figure 14-20. This electronic ignition system is equipped with a *reluctor*. Connect *voltmeter* A between the *dual ballast resistor* and *ground*. Turn the ignition switch on. The reading should be about 12 volts. If the reading is lower, check the ignition switch and the *wiring* between the *battery* and dual ballast resistor.

Connect *voltmeter* B between the dual ballast resistor and ground. Turn the ignition switch on. The reading should be between 1 and 3 volts. If there is no voltage, replace the ballast resistor. If the reading is 12 to 13 volts, check the *control unit ground* and *wiring* between the ballast resistor and the control unit. If no problem is revealed, replace the control unit.

Connect *voltmeter* C between the positive (+) terminal of the ignition coil and the ground. Turn the ignition switch on. The voltmeter should read 6.9 to 7.5 volts. If the reading is 12 to 13 volts, check the ignition switch, control unit ground, and wiring between the negative (−) ignition coil terminal and the control unit. If no problem is revealed, replace the control unit. Replace the ballast resistor if the reading is zero. Have an assistant crank the engine. The voltage reading should be 10 to 11 volts. If voltage falls to 6 to 7.5 volts, check the ignition switch and the ballast resistor *bypass circuit*.

Connect *voltmeter* D between the negative (−) terminal of the ignition coil and the ground. Turn the ignition switch on. The reading should be 1.5 to 5 volts. A reading of 12 to 13 volts or a reading of zero volts indicates that the control unit should be replaced.

Disconnect the two-wire *distributor connector* and connect *voltmeter E*. Use the low voltmeter scale. Have an assistant crank the engine. The voltmeter needle should vibrate back and forth around zero volts. If no deflection occurs, replace the magnetic pickup of the distributor.

Ford Motor Company. For basic testing of an electronic ignition system by Ford Motor Company (Figure 14-21), refer to the wiring diagram in Figure 14-22. This electronic ignition system is equipped with an *armature*. Connect *voltmeter A* between the positive (+) *BAT terminal* of the *ignition coil* and *ground* as shown. Turn the ignition switch on. The reading should be 6.5 to 8.5 volts. If the reading is 12 volts, check the resistor *bypass circuit*. If the reading is zero, check the *primary resistor lead*, the *ignition switch*, and the *wiring* between the *battery* and the ignition coil. Have an assistant crank the engine. The reading should be .3 to 1.5 volts. A reading in the range of 4 to 7 volts indicates that the resistor bypass circuit should be checked.

Next, connect *voltmeter* B between the negative (−) DEC terminal of the ignition coil and the ground. Turn the ignition switch on. The reading should be .3 to 1.5 volts. A reading of 12 to 13 volts indicates that the *modulator assembly* should be replaced. A reading of zero volts also indicates modulator assembly replacement.

Disconnect the three-wire *distributor connector* and connect *voltmeter* C. Have an assistant crank the engine. Use the lowest voltmeter scale.

CAUTION: To protect the meter, start with the range selector knob on the highest scale, then switch to the lowest, as discussed in Unit 4.

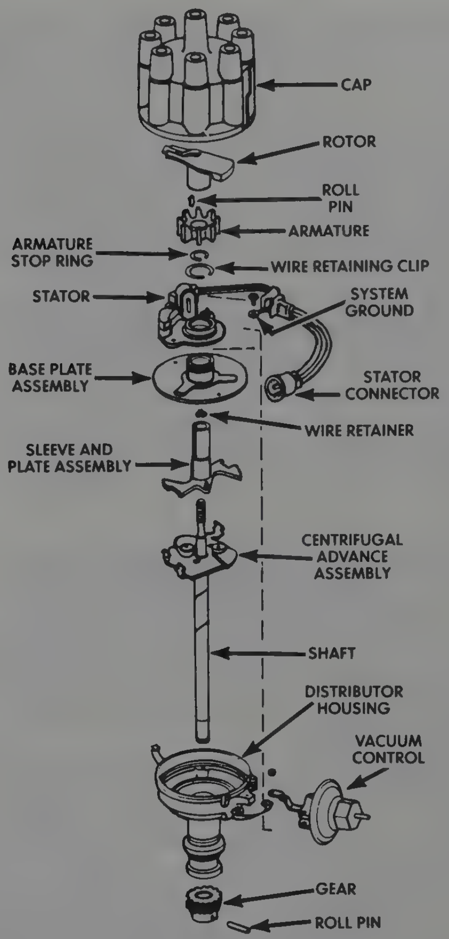

CAP
ROTOR
ROLL PIN
ARMATURE
ARMATURE STOP RING
WIRE RETAINING CLIP
STATOR
SYSTEM GROUND
BASE PLATE ASSEMBLY
STATOR CONNECTOR
WIRE RETAINER
SLEEVE AND PLATE ASSEMBLY
CENTRIFUGAL ADVANCE ASSEMBLY
SHAFT
DISTRIBUTOR HOUSING
VACUUM CONTROL
GEAR
ROLL PIN

Figure 14-21. Ford Motor Company electronic distributor nomenclature. (Courtesy of C. E. Niehoff & Co.)

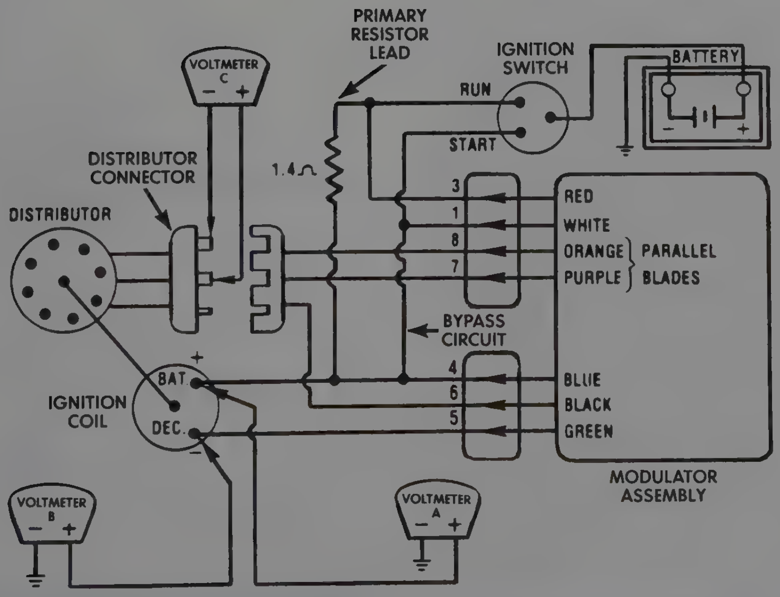

PRIMARY RESISTOR LEAD
IGNITION SWITCH
BATTERY
RUN
START
VOLTMETER C
− +
DISTRIBUTOR CONNECTOR
DISTRIBUTOR
1.4Ω
3
1
8
7
RED
WHITE
ORANGE
PURPLE
PARALLEL BLADES
BYPASS CIRCUIT
+
BAT.
IGNITION COIL
DEC.
−
4
6
5
BLUE
BLACK
GREEN
MODULATOR ASSEMBLY
VOLTMETER B
− +
VOLTMETER A
− +

Figure 14-22. Voltmeter connection for testing the Ford Dura Spark II electronic ignition. (Courtesy of Ford Motor Company)

The voltmeter needle should vibrate back and forth around zero volts. If there is no deflection, remove and inspect the distributor cap and rotor. Also, inspect the armature (Figure 14-21) for damage and tightness of fit. The armature should rotate when the engine is cranked. Replace components as necessary. If there is still no deflection, replace the stator.

General Motors Corporation. The General Motors unitized ignition (Figure 14-23) has been used in several engine applications, including V-6, V-8, and L-6 (flat-head, or L-head, design) engines. Connections for basic testing and testing procedures are shown in Figure 14-24.

Breaker Point Distributor Testing

No spark or a weak spark may be due to any one of several problems in a breaker point distributor. Three common problems are faulty breaker points, faulty condenser, or faulty primary circuit wiring.

The tune-up technician should first remove the distributor cap and visually inspect the breaker points. Open the breaker points and inspect the contact surfaces for oily or burned contact surfaces, which would prevent current flow and thus prevent starting. While an assistant cranks the engine, make sure the points are opening and closing properly. Inspect all the visible primary circuit wires inside the distributor to make sure that they are connected properly and that there are no opens or grounds.

The condenser can be defective because of improper capacity, or capacitance, insulation breakdown, or series resistance. Turn on the ignition switch and connect a *continuity test light* between the distributor primary terminal and a ground. The light should go on when the ignition breaker points open. No light indicates that the condenser may be grounded internally. To eliminate this possibility, repeat the test, making sure that the condenser case is disconnected (not grounded externally). If the spark is restored, replace the condenser. (More complete analysis can be performed with an oscilloscope as described later in this unit.) If no problem is revealed with the breaker points and condenser, reinstall the distributor cap.

The next area to check is that of breaker point **dwell**. Dwell (sometimes called cam angle) is the number of degrees the *breaker cam* rotates

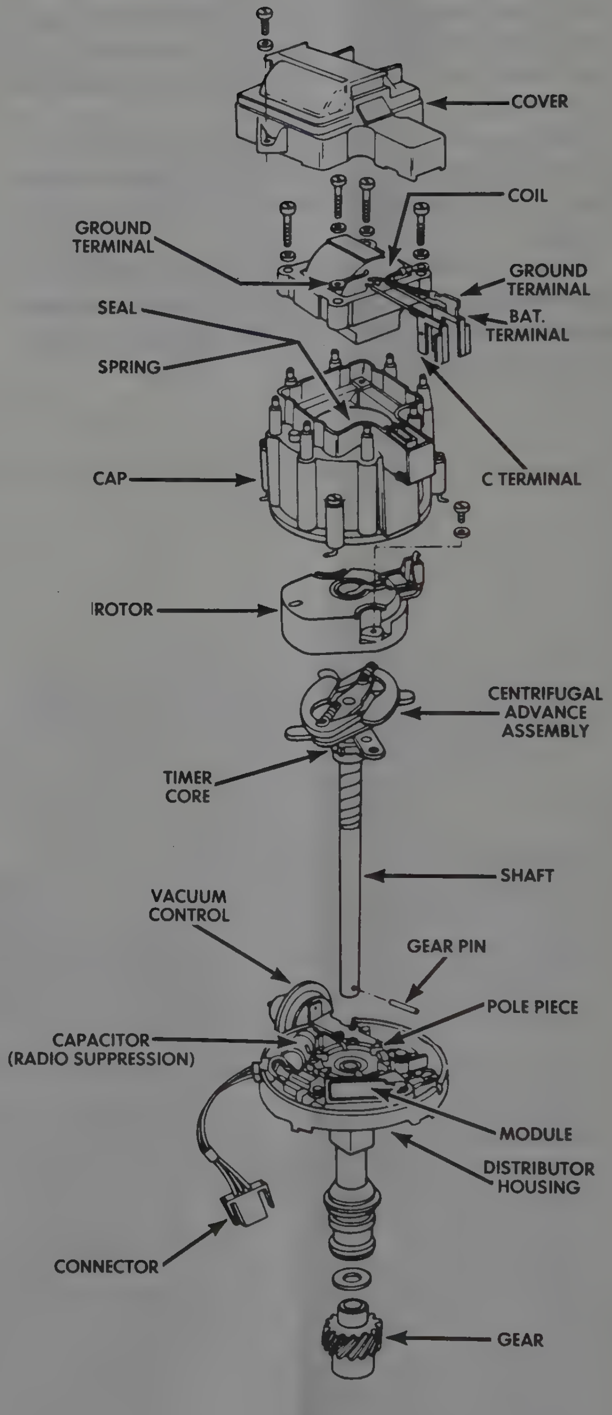
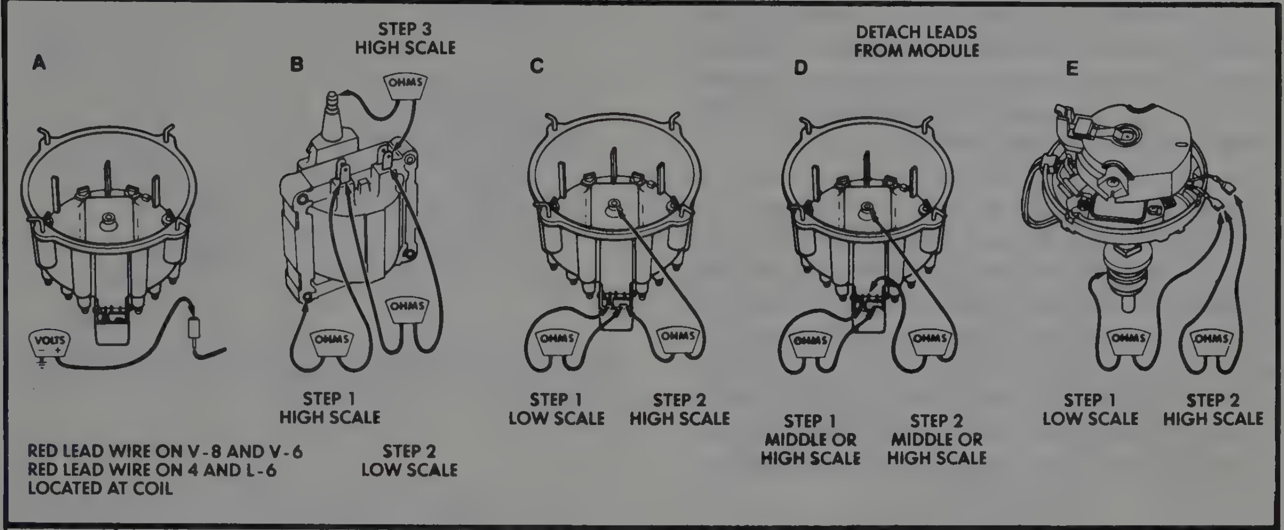


Figure 14-23. General Motors Corporation unitized electronic ignition distributor nomenclature. (Courtesy of C. E. Niehoff & Co.)


A
STEP 3
HIGH SCALE
B
C
DETACH LEADS
FROM MODULE
D
E
OHMS
VOLTS
STEP 1
HIGH SCALE
STEP 1
LOW SCALE
STEP 2
HIGH SCALE
STEP 1
MIDDLE OR
HIGH SCALE
STEP 2
MIDDLE OR
HIGH SCALE
STEP 1
LOW SCALE
STEP 2
HIGH SCALE
RED LEAD WIRE ON V-8 AND V-6
RED LEAD WIRE ON 4 AND L-6
LOCATED AT COIL
STEP 2
LOW SCALE

			VOLTMETER OR OHMMETER READINGS	
DIAGRAM REFERENCE	**PROCEDURE**	**ACCEPTABLE**	**HIGHER**	**LOWER**
A	Disconnect single red lead wire at Cap on V-6 and V-8 or at Coil on 4 and L-6. Connect voltmeter between lead wire and ground. Ignition Switch ON.	12-13	— —	0 Check Ignition Switch and wiring between Battery and Coil
B	For 4 and L-6 engines. Connect ohmmeter as in diagram **B**. Ignition Switch OFF Step **1.** High Scale Step **2.** Low Scale Step **3.** High Scale	**1.** Infinite **2.** 0.5 to 1.0 **3.** 6,000-30,000	**1.** — — **2.** Replace Coil **3.** Replace Coil	**1.** Replace Coil **2.** — — **3.** Replace Coil
C	For V-6 and V-8 engines: Early 1975 and Prior. Remove Cap. Spark Plug wires need not be removed. Connect ohmmeter as in diagram **C**. Ignition Switch OFF Step **1.** Low Scale Step **2.** High Scale	**1.** 0.5 to 1.0 **2.** 6,000-30,000	**1.** Replace Coil **2.** Replace Coil	**1.** — — **2.** Replace Coil
D	For V-6 and V-8 Engines: After late 1975. Spark plug wires need not be removed. Connect ohmmeter as in diagram **D**. Ignition Switch OFF. Step **1.** Low Scale Step **2.** High Scale	**1.** 0.5 to 1.0 **2.** 6,000-30,000	**1.** Replace Coil **2.** Replace Coil	**1.** — **2.** Replace Coil
E	Connect ohmmeter as in diagram **D**. Observe ohmmeter thru vacuum range by introducing outside vacuum or manually moving vacuum advance control arm. Ignition switch OFF. Step **1.** Middle or High Scale Step **2.** Middle or High Scale	**1.** Infinite **2.** 500 to 1,500	**1.** — — **2.** Replace Pole Piece	**1.** Replace Pole Piece **2.** Replace Pole Piece

If above checks provide acceptable readings, test Module by substitution. Module can be checked only with specifically designed instruments.

Figure 14-24. Connections and procedures for testing a General Motors Corporation unitized ignition. (Courtesy of C. E. Niehoff & Co.)

while the *breaker points* are closed (Figure 14-25). Dwell is changed by increasing or decreasing the gap between the two breaker points. The dwell increases as the breaker point opening is decreased and decreases as the breaker point opening is increased.

Correct breaker point opening, or dwell, is important, especially during starting and low speed operation. If the breaker points are set too close, arcing and burning will occur, causing difficult starting and poor low-speed performance. If breaker points are too wide, dwell will be too little to allow saturation of the primary coil at high engine speeds, resulting in a weak spark. The dwell may be measured with a dwell meter after the engine is running or while being cranked.

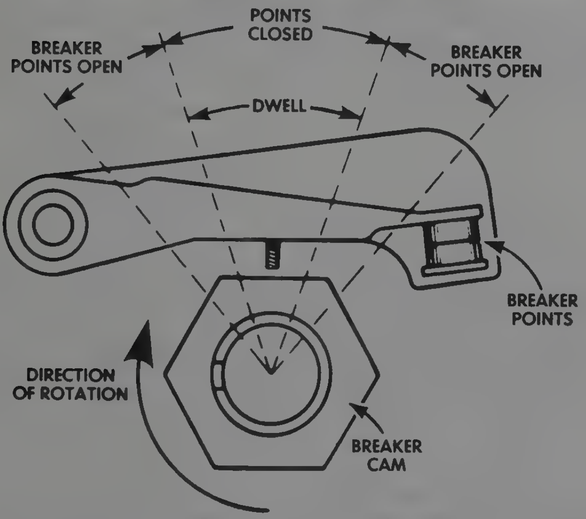

POINTS CLOSED
BREAKER POINTS OPEN
BREAKER POINTS OPEN
DWELL
BREAKER POINTS
DIRECTION OF ROTATION
BREAKER CAM

Figure 14-25. Dwell is the number of degrees the breaker cam rotates while the breaker points are closed. (Courtesy of Chevrolet Motor Division, General Motors Corporation)

A typical dwell meter (Figure 14-26) has two *leads*. The leads are clipped together and the meter calibrated (follow manufacturer's instructions). The selector switch is turned to a position corresponding to the number of cylinders of the engine. This adjusts the meter for the number of breaker cam lobes, since there is a lobe for each cylinder. One lead is connected to the ignition coil negative (—) or DIST terminal and the other to ground.

The engine is cranked and the *meter scale* observed. Compare the reading with specifications. Adjust the dwell by opening or closing the breaker points. (The method used will depend upon the type of breaker points in the distributor.) If the dwell is too large, the *stationary breaker point* should be moved in toward the breaker cam (Figure 14-27). This will increase breaker point opening and decrease the dwell. If the dwell is too small, the *stationary breaker point* should be moved away from the breaker cam (Figure 14-28). This will decrease the breaker point opening and increase the dwell.

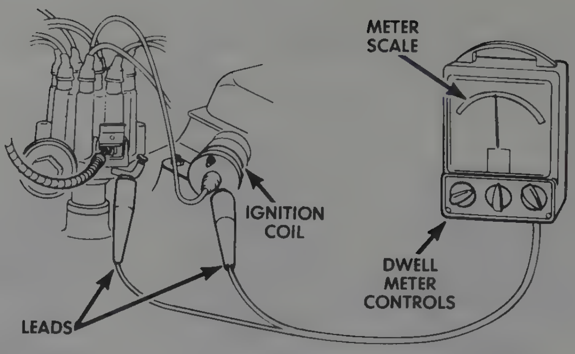

METER SCALE
IGNITION COIL
DWELL METER CONTROLS
LEADS

Figure 14-26. Typical dwell meter and its connections. (Courtesy of Delco Remy, Division of General Motors Corporation)

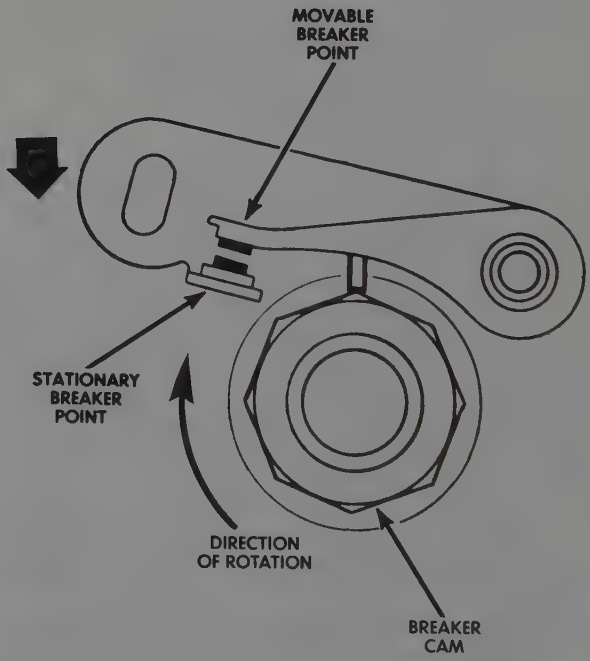

MOVABLE BREAKER POINT
STATIONARY BREAKER POINT
DIRECTION OF ROTATION
BREAKER CAM

Figure 14-27. Move the stationary breaker point toward the breaker cam to decrease dwell. (Courtesy of Delco Remy, Division of General Motors Corporation)

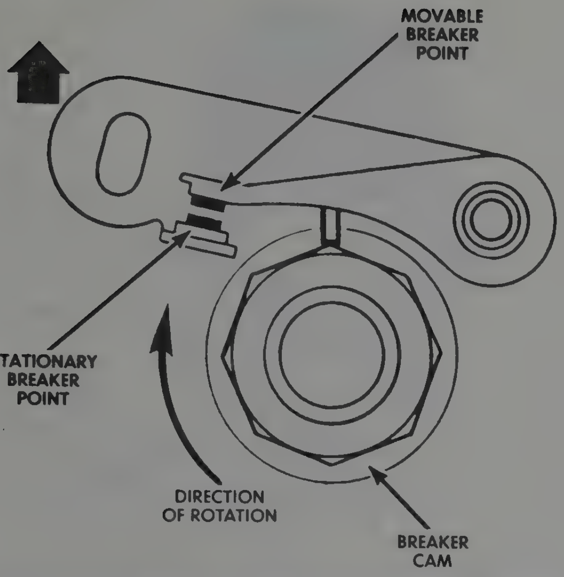


Figure 14-28. Move the stationary breaker point away from the breaker cam to increase dwell. (Courtesy of Delco Remy, Division of General Motors Corporation)

IGNITION TIMING CHECK

The distributor, if properly adjusted, automatically provides the correct spark advance for best performance and economy at any given engine speed or load. If ignition basic timing is too far retarded or too far advanced, engine performance will be poor. An ignition timing test shows the timing of the spark in relation to the No. 1 piston position. Ignition timing at speeds above idle can best be tested with a timing light and magnetic timing tester, or by removing the distributor from the engine and testing it with a distributor tester.

Basic timing, as discussed in Unit 13, is often checked with a *timing light* (Figure 14-29). (Check the appropriate service manual for specification and hookup.) The typical timing light has a set of *leads* connected to the vehicle's battery for power. An *induction pickup* goes around the spark plug cable. Other types of timing lights use an *adapter* (Figure 14-30) that allows the spark plug cable to be connected to the timing light and the spark plug at the same time.

Some lights are connected into a larger tester unit or receive power from a 115 VAC outlet. Electrical energy is stored in large capacitors inside some timing lights. A high-voltage impulse from the ignition system causes this energy to be discharged into the flash tube of the timing light, creating a bright flash of light. The impulse is received by connecting a lead from the timing light to the vehicle's No. 1 spark plug wire.

When the vehicle's engine is running, the ignition impulse causes the timing light to flash

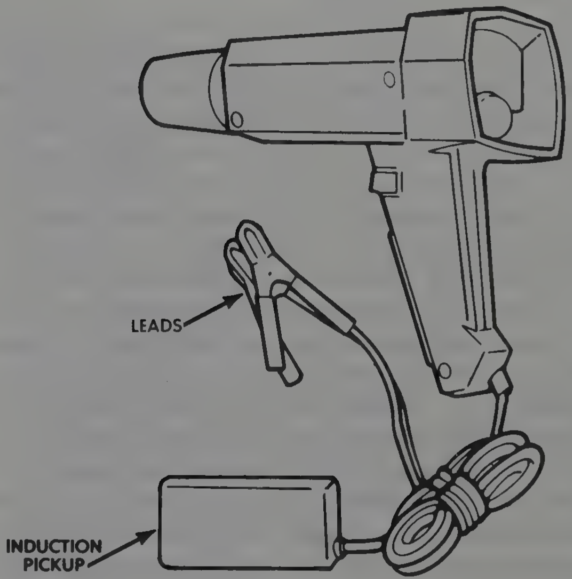


Figure 14-29. Basic ignition timing is checked with a timing light. (Courtesy of Ford Motor Company)

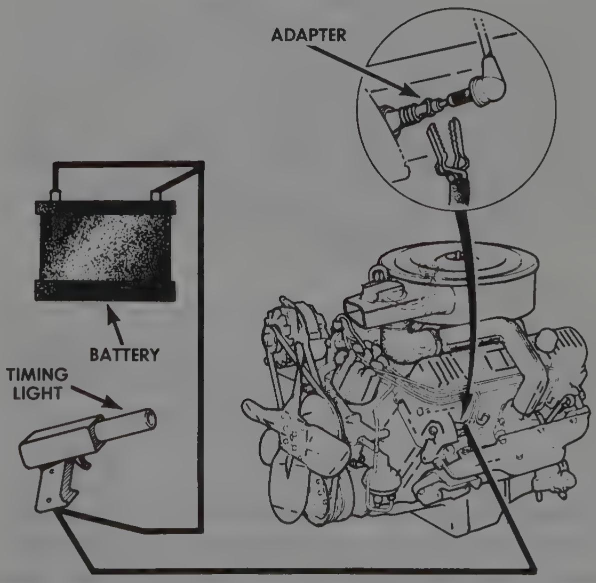


Figure 14-30. Typical hookup for a timing light with an adapter. (Courtesy of Chevrolet Motor Division, General Motors Corporation)

each time the No. 1 spark plug receives high-voltage current. This flashing light is directed at the timing marks (*stationary pointer* and *timing or reference mark*) as shown in Figure 14-31. (Also see Unit 13, under the heading of "Basic Timing.") The light flashing on and off rapidly makes the timing mark appear to be stopped, or stationary.

The timing marks may be graduated from top dead center (TDC) through varying degrees before top dead center (BTDC) and after top dead center (ATDC). The timing marks may be inscribed on either the stationary pointer or on the crankshaft pulley or damper. Vehicle manufacturers provide timing mark specifications. This information is usually found in the service manual or an under-the-hood label.

NOTE: On some vehicles, the vacuum lines (or electrical sensors) must be disconnected when the timing is being checked. Follow vehicle manufacturer instructions for this procedure.

Start the engine and set the idle to that specified for the type of engine being checked. Use the timing light to observe the position of the timing marks (Figure 14-31). If the indicated ignition timing is not within specifications, loosen the distributor *hold-down clamp* and rotate the distributor (Figure 14-32) so that the reference mark and stationary pointer are aligned. (Turning the distributor in a direction opposite rotor rotation advances timing. Turning the distributor in the same direction retards timing.) Secure the distributor (Figure 14-33) after the timing has been properly set. Recheck the adjustment with the timing light. (Replace any vacuum lines or electrical sensors that may have been removed.)

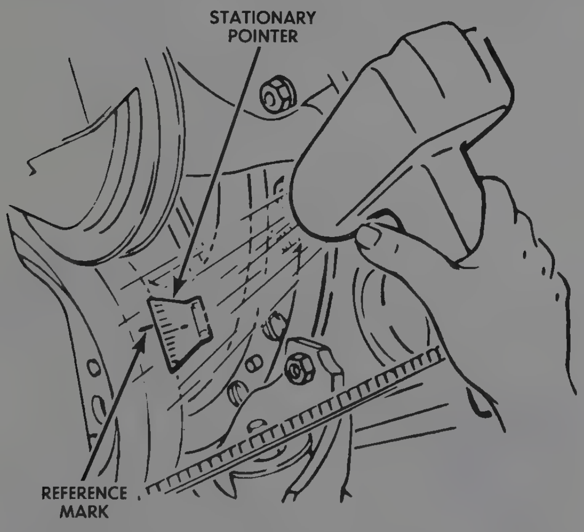


Figure 14-31. Basic timing is checked with a timing light. (Courtesy of Delco Remy, Division of General Motors Corporation)

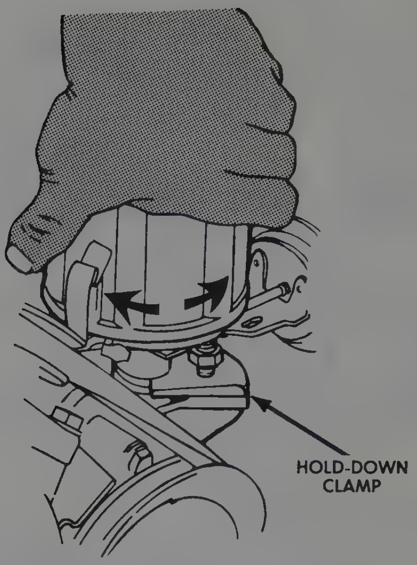


Figure 14-32. Basic timing is changed by rotating the distributor. (Courtesy of Delco Remy, Division of General Motors Corporation)

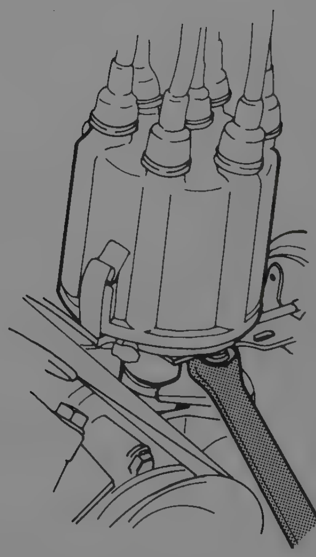


Figure 14-33. When the timing is set to specifications, secure the distributor by tightening the hold-down clamp. (Courtesy of Delco Remy, Division of General Motors Corporation)

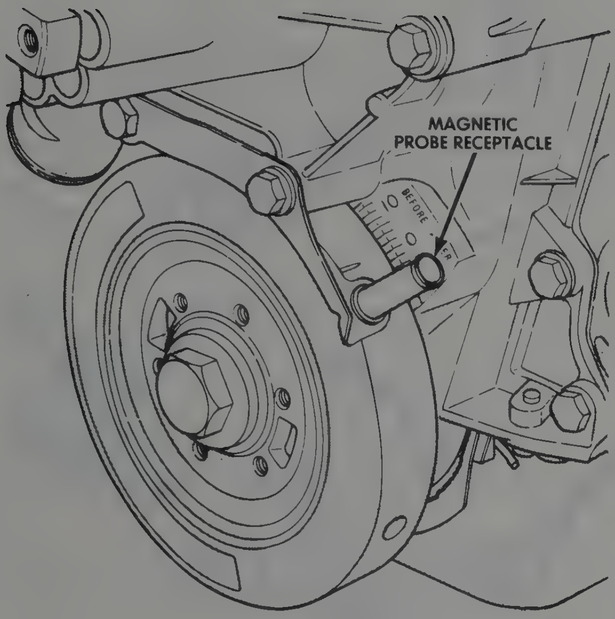


Figure 14-34. A magnetic probe receptacle located over the front pulley allows the use of a magnetic timing tester. (Courtesy of Chrysler Corporation)

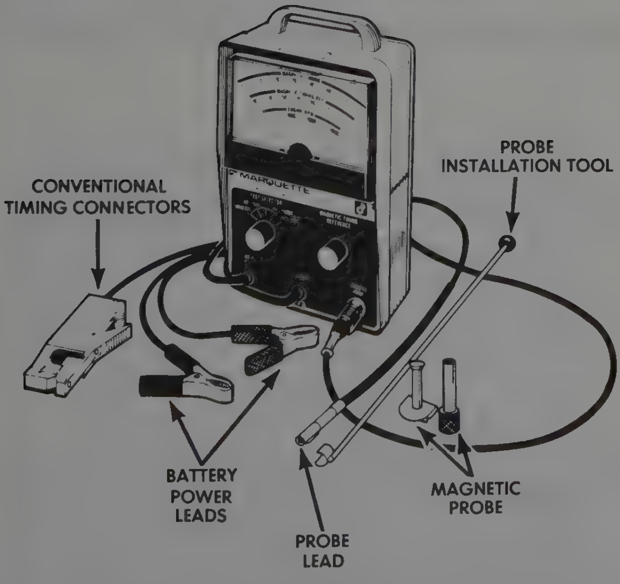


Figure 14-35. Typical magnetic timing tester. (Courtesy of Marquette Products, Automotive Division of Applied Power, Inc.)

Many late-model vehicles are equipped with a *magnetic probe receptacle* (Figure 14-34) to accommodate a *magnetic timing tester* (Figure 14-35) which senses engine crankshaft position from a magnet in the front pulley. (Be sure to follow manufacturer's instructions for correct hookup of a magnetic timing tester.)

USING AN OSCILLOSCOPE TO TROUBLESHOOT THE IGNITION SYSTEM

The procedure for connecting and using a particular oscilloscope is provided in an instruction manual supplied by the manufacturer. A typical hookup diagram is shown in Figure 14-36.

Most oscilloscope manufacturers specify that the vehicle be at operating temperature and that idle RPM be increased to between 1,000 and 1,500 RPM. Below 1,000 RPM, many oscilloscopes are unstable and may produce misleading results. At speeds above 1,500 RPM the ignition coil and condenser section of the pattern begins to disappear and cannot be easily interpreted.

The oscilloscope instruction manual provides illustrations of acceptable display patterns for ignition systems. In addition, **abnormal display patterns** resulting from a problem in the *firing, intermediate,* or *dwell* sections are shown. Therefore, the tune-up technician can use the instruction manual to help determine the cause of an abnormal display pattern. With experience in recognizing the abnormal patterns produced by common malfunctions, the technician's dependence upon the instruction manual will decrease. This unit explains how to analyze various abnormal patterns. *Unit 4 contains basic oscilloscope information.*

Checking Oscilloscope Patterns — Firing Section

An inspection of the *firing section* of an engine's oscilloscope display pattern provides information about secondary circuit operation. Some of the other ignition system components that may be tested are the spark plugs, the spark plug cables, the connectors, the rotor, the rotor cap, and the ignition coil windings. A normal secondary firing pattern for one cylinder is shown in Figure 14-37.

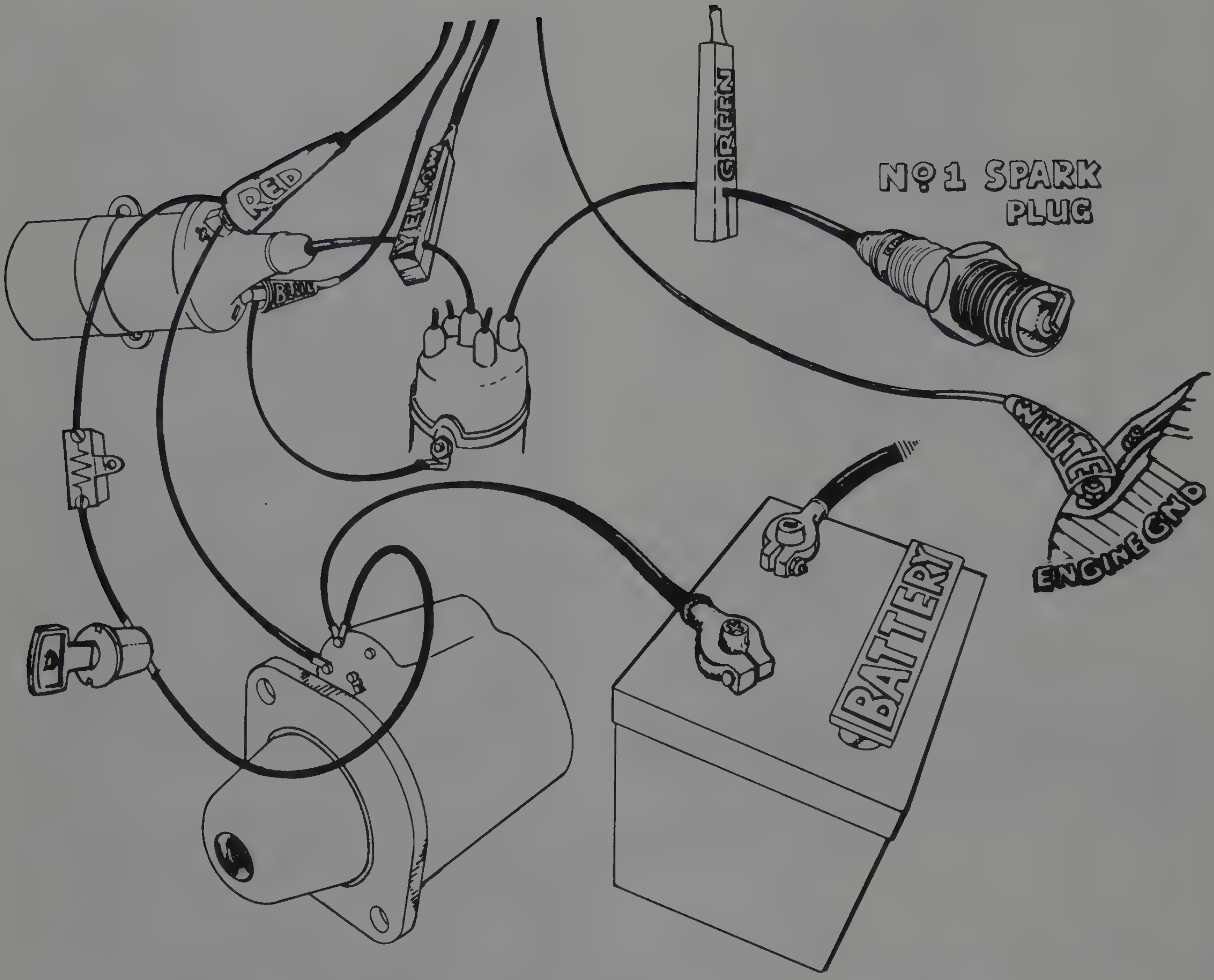

RED
YELLOW
BLUE
GREEN
Nº 1 SPARK PLUG
WHITE
ENGINE GND
BATTERY

Figure 14-36. Typical oscilloscope hookup diagram. (Courtesy of Marquette Products, Automotive Division of Applied Power, Inc.)

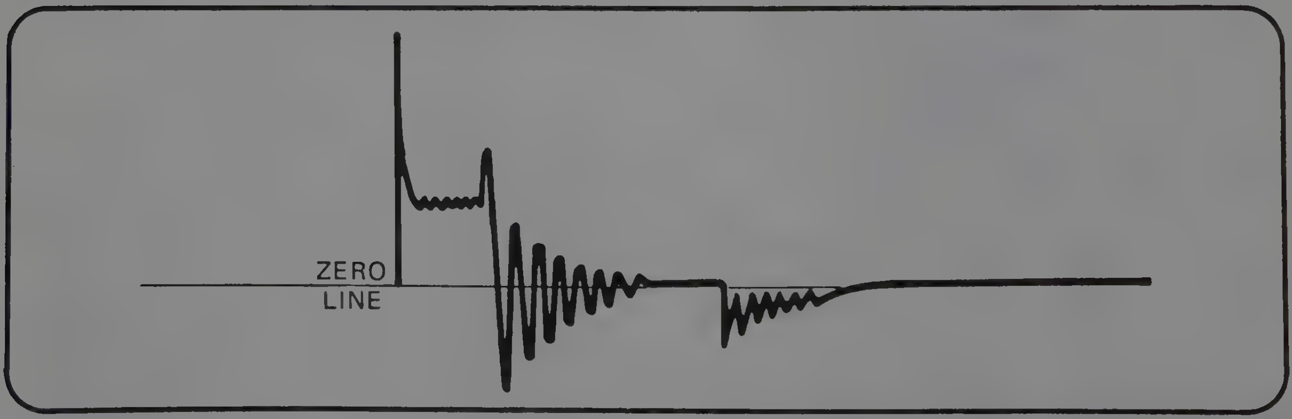


Figure 14-37. Normal secondary firing pattern for one cylinder. (Courtesy of Nissan Motor Corporation in U.S.A.)

In Figure 14-38, it is obvious that one of the patterns in the parade display has an unusual firing section. The problem is in the No. 3 cylinder. The energy that is not consumed in the spark shows up as ignition coil and condenser oscillations. In the case of this particular cylinder, no energy is consumed in the spark, so all of the energy is absorbed in ignition coil and condenser oscillations. The problem could be an open or shorted spark plug or spark plug cable.

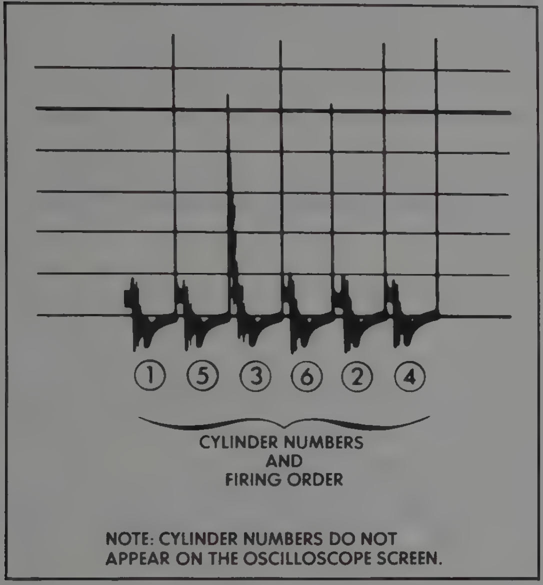


Figure 14-38. Parade display showing a problem at the No. 3 cylinder. (Courtesy of Chevrolet Motor Division, General Motors Corporation)

Firing voltage is the amount of voltage required to produce a spark across the electrodes of a spark plug. The normal firing voltages of all the cylinders can easily be measured by observing the *firing lines* or *spikes*. The firing voltage should be within a range of about 5 to 8 kilovolts (KV) at engine speeds of 1,500 RPM. When all the firing voltages appear fairly uniform but measure higher than normal (Figure 14-39), the problem is usually worn spark plug electrodes, retarded ignition timing, lean air-fuel mixture, excessive rotor gap, or a high resistance in the coil secondary winding. Uneven firing voltages (Figure 14-40) indicate worn spark plugs, unbalanced air-fuel mixture, breaks in spark plug cables, or worn distributor cap.

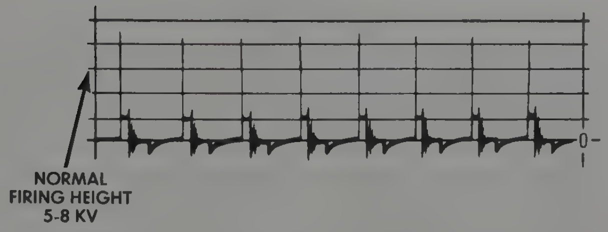


Figure 14-39. The firing voltages in this parade display are higher than normal. (Courtesy of Sun Electric Corporation)

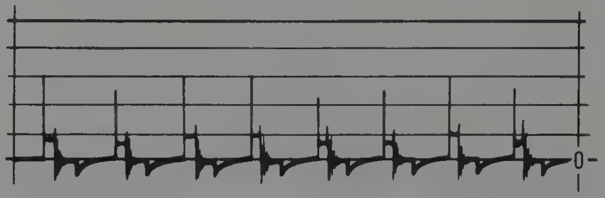


Figure 14-40. The firing voltages in this parade display are uneven. (Courtesy of Sun Electric Corporation)

Available voltage is a term used to indicate the maximum voltage an ignition system is capable of producing under a given operating condition. Because of its operating characteristics, an ignition coil will produce its maximum secondary voltage whenever it attempts to fire an impossible spark plug gap. An example of this would be when a spark plug cable is removed from a spark plug and held at a distance from ground. Ignition system design is such that available voltage is always greater than the ignition required under most operating conditions.

The difference between available voltage and firing voltage is commonly referred to as **ignition reserve**. Measuring the available voltage provides a quick means of determining the overall efficiency of the secondary system. **CAUTION: Some electronic ignition systems can be damaged by this test. Refer to the vehicle shop manual. Prolonged testing can also cause the catalytic converter to overheat.**

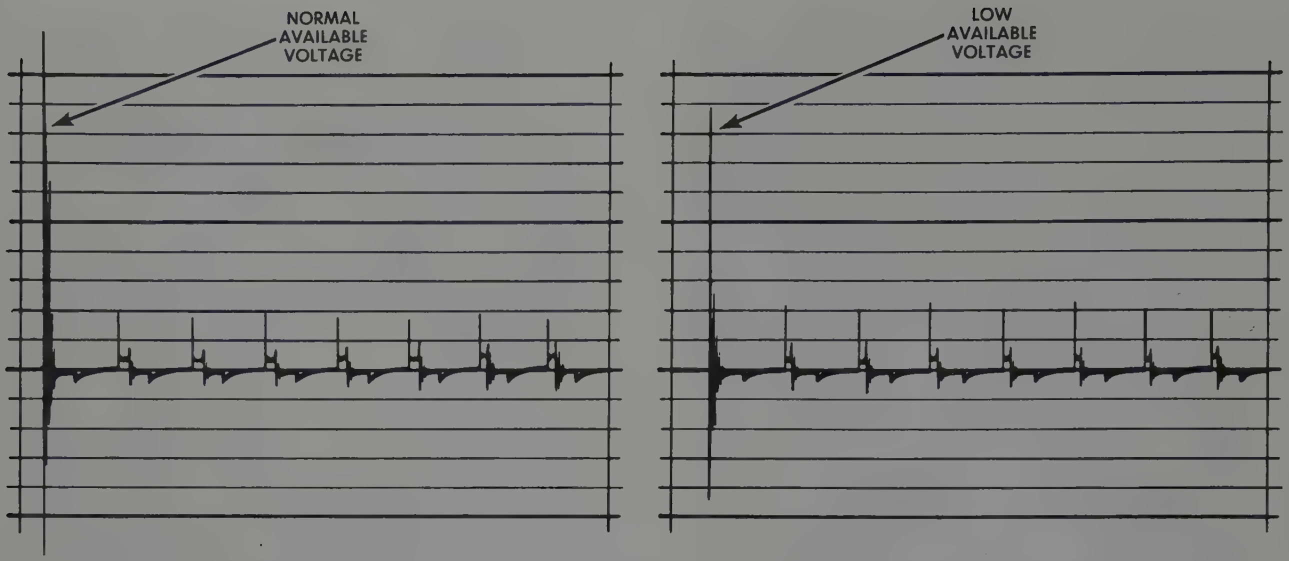


Figure 14-41. Comparison of normal available voltage with low available voltage. (Courtesy of Sun Electric Corporation)

In Figure 14-41, two eight-cylinder engines on parade display have their No. 1 spark plug cables disconnected. *Normal available voltage* can be measured using the appropriate KV scale on the oscilloscope screen. *Low available voltage* can be caused by higher than normal resistance in the primary circuit, less than specified breaker point dwell, a defective ignition coil, secondary circuit insulation leakage, or low primary voltage.

Secondary circuit polarity is easily inspected with an oscilloscope. **Reversed polarity** is caused by a reversed connection at the ignition coil primary terminals, an incorrect ignition coil in the vehicle, or a battery that is connected backwards (reversed). The pattern for reversed polarity is shown in Figure 14-42. The firing lines are below the base line, or zero line, or are said to be "upside down."

Excessive resistance in the secondary circuit is indicated by a *spark line* that begins at a comparatively high point on the firing line and slants downward excessively toward the intermediate section. High resistance at the No. 3 cylinder is shown in Figure 14-43. Spark duration is reduced considerably, and excessive oscillations are evident on the spark line. High resistance causing this type of pattern may be in the spark plug, spark plug cable, or spark plug cable connections.

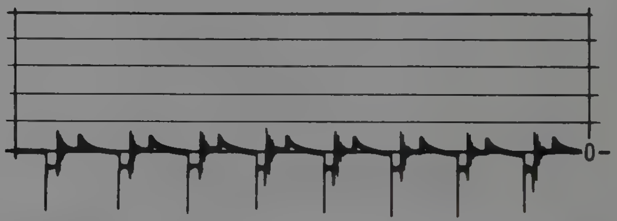


Figure 14-42. Firing lines below the base line, or zero line, indicate reversed polarity. (Courtesy of Sun Electric Corporation)

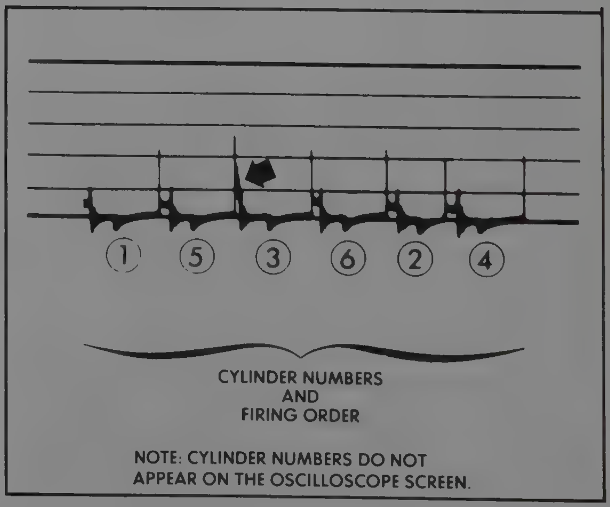

① ⑤ ③ ⑥ ② ④
CYLINDER NUMBERS AND FIRING ORDER
NOTE: CYLINDER NUMBERS DO NOT APPEAR ON THE OSCILLOSCOPE SCREEN.

Figure 14-43. High resistance is shown (see arrow) in this parade display pattern for the No. 3 cylinder. (Courtesy of Chevrolet Motor Division, General Motors Corporation)

Spark plug voltage requirements may vary considerably depending on several factors as discussed earlier in this unit. In particular, the effect of certain spark plug conditions such as rounded spark plug electrodes, extremely wide air gaps, and fouling is generally more evident when the engine is operating under a load.

One simple method of loading an engine for test purposes is by **snap acceleration**. This is accomplished by quickly opening the throttle valve and allowing the engine to accelerate from 1,000 RPM to approximately 2,000 RPM before closing the throttle valve. The rapid opening of the throttle valve momentarily places a load on the engine. During this momentary period, the firing line and spark line should be observed for any unusual characteristics. Normally, the requirements of all cylinders will rise under this condition, but the firing and spark lines of all patterns should remain uniform in appearance.

The voltage requirements of all spark plugs continually increase as a result of normal electrode wear. Increased voltage requirements are indicated by higher than normal firing lines or shorter spark lines while the engine is under load. Watch for individual firing voltages that are considerably different from those of the other cylinders of the engine.

In this unit, only a few types of abnormal firing section patterns are given. An oscilloscope instruction manual shows examples of many more. Only through observation of abnormal patterns and comparison with the acceptable patterns shown in the manual can the tune-up technician learn to recognize typical problems.

Checking Oscilloscope Patterns — Intermediate Section

The *intermediate section* is usually observed as a series of diminishing oscillations. It can be easily examined when each cylinder's pattern is displayed individually in the raster, expanded, or parade mode. The number of oscillations observed depends on a number of factors such as dwell, engine speed, spark duration, ignition coil saturation, and ignition coil and condenser condition.

The rate at which the oscillations diminish should be noted. Normally, they will diminish gradually. However, should the ignition system contain a shorted ignition coil or leaky condenser, the oscillations will diminish to zero rapidly.

If both the ignition coil and condenser oscillations and the points-close signal are missing, or if the oscillations are very small (Figure 14-44), the ignition coil or coil tower is probably defective. A parade display pattern shown in Figure 14-45 appears to have fewer than the normal number of oscillations. This is, however, a normal pattern that might be observed (1) when testing igntion systems that have dual point or dual pickup distributors, (2) when testing at speeds higher than 1,500 RPM, or (3) when the dwell is set much higher than specified.

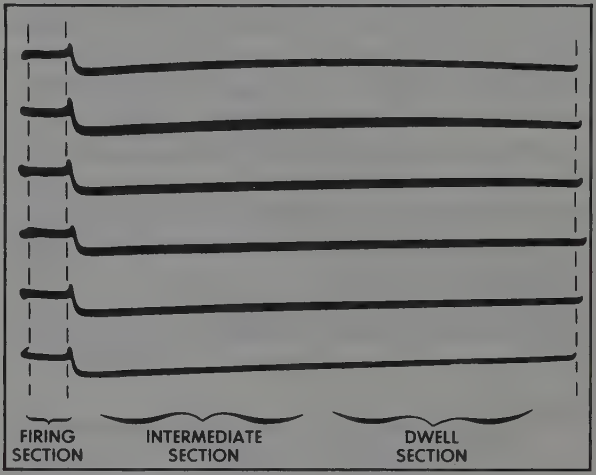


Figure 14-44. The lack of oscillations in the intermediate section of this raster display pattern indicates that the ignition coil or coil tower is defective. (Courtesy of Chevrolet Motor Division, General Motors Corporation)

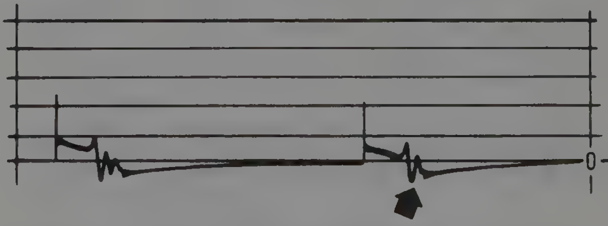


Figure 14-45. The intermediate section of this parade display pattern shows few oscillations (see arrow) but is considered normal for ignition systems that use dual point or dual pickup distributors. (Courtesy of Sun Electric Corporation)

Checking Oscilloscope Patterns — Dwell Section

The *dwell section* of the pattern provides information about the operation of the primary circuit which utilizes breaker points. Breaker point action, dwell, and cam lobe accuracy may be indicated.

The dwell section begins when the breaker points close, and it continues to the instant that the breaker points open to fire the next cylinder. The breaker point closing and opening signals should be carefully observed. As discussed in Unit 4, the closing of the breaker points is shown as a short vertical line followed by a series of diminishing oscillations. The first line should be longer than any of the oscillations that follow.

If the first line (oscillation) is not as long as one or more of the lines that follow, poor breaker point contact is indicated. On the other hand, should the oscillations diminish and then renew themselves, a *breaker point bounce condition* is indicated (Figure 14-46). In this condition, the breaker point spring is weak, so the breaker points bounce apart slightly after they are closed. As a result, full coil saturation may be prevented. This problem is especially evident at high RPM.

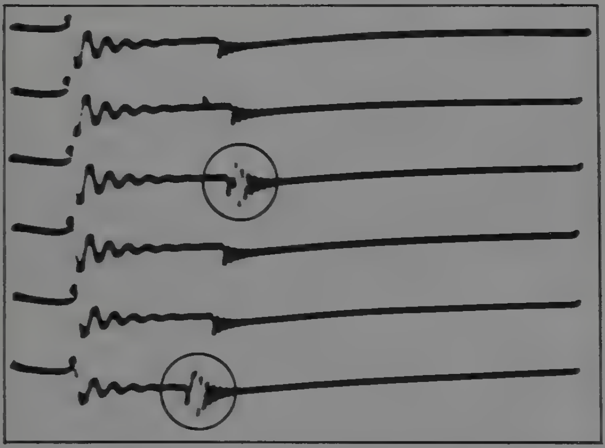


Figure 14-46. This raster display pattern indicates breaker point bounce (see circles). (Courtesy of Chevrolet Motor Division, General Motors Corporation)

As discussed in Unit 4, when the breaker points open, the end of the dwell section should appear as a right angle formed by the horizontal dwell line and the vertical firing line of the next pattern. A *breaker point arcing condition* (Figure 14-47) upon opening of the breaker points is shown as a bright blip at the beginning of the trace just prior to the firing line.

Proper dwell is essential to efficient operation of the ignition system. Dwell must be set to a specific value to assure adequate ignition coil saturation to meet the firing requirements at all engine speeds. When the display pattern from any one cylinder is extended horizontally by using the horizontal control knob, it can completely fill the space between the two vertical lines on the oscilloscope screen. The distance from breaker points closing to breaker points opening can then be measured on the dwell scale.

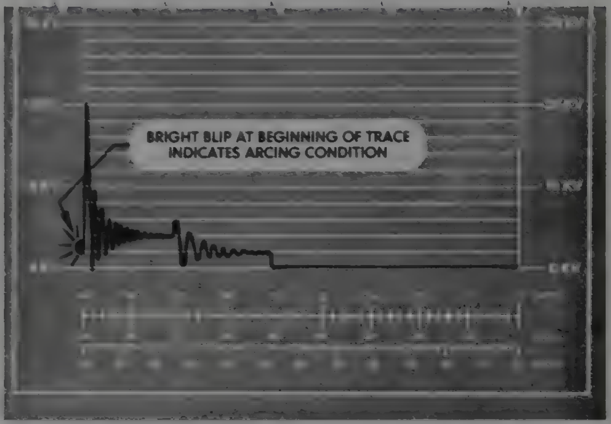


Figure 14-47. This expanded display pattern shows a breaker point arcing condition. (Courtesy of Nissan Motor Corporation in U.S.A.)

Figure 14-48 shows one cylinder's pattern of an eight-cylinder engine with a dwell of 26½°. The *raster display pattern* in Figure 14-49 shows a *dwell section* that is very short. This is likely to cause a high-speed misfire, because the breaker points are closed for such a short period of time that the ignition coil cannot become properly saturated.

The accuracy of the cam lobes helps determine the ignition timing relationship of all cylinders. Should one or more cam lobes become

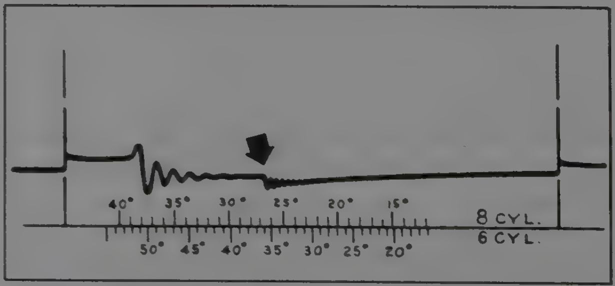


Figure 14-48. The dwell on this display pattern is shown as 26½° (see arrow). (Courtesy of Sun Electric Corporation)

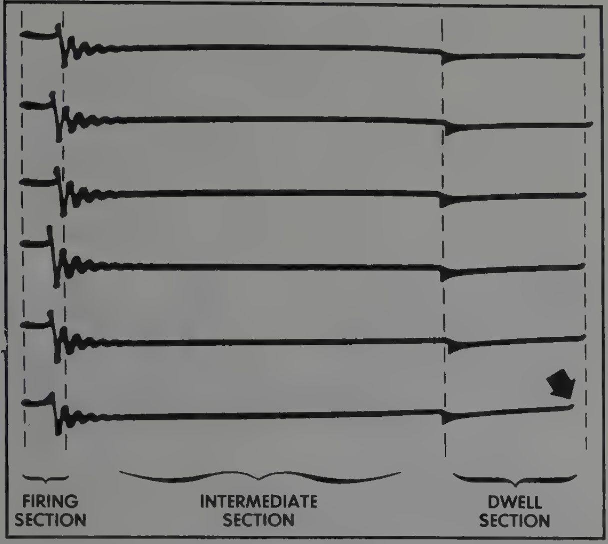


Figure 14-49. This raster display pattern shows a short dwell (see arrow). (Courtesy of Chevrolet Motor Division, General Motors Corporation)

worn, or should the distributor shaft be bent, uneven timing of the various cylinders results.

Cam lobe accuracy can be checked on a *superimposed display pattern* or a *raster display pattern*. A superimposed display pattern depicting cam lobe wear is shown in Figure 14-50. It indicates a variation at the breaker point closing of an eight-cylinder engine.

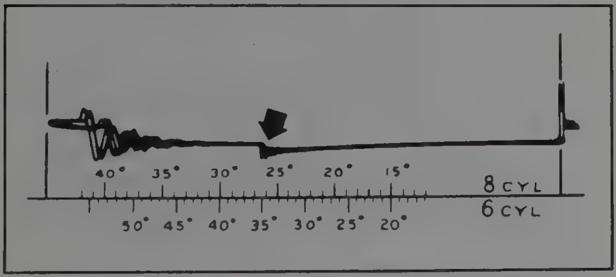


Figure 14-50. This superimposed display pattern shows a variation at the breaker point closing (see arrow). (Courtesy of Chevrolet Motor Division, General Motors Corporation)

A raster display pattern depicting another cam lobe problem is shown in Figure 14-51. Here an *S curve* or *S pattern* is caused by an off-center breaker cam, a bent distributor shaft, an off-center distributor drive, or a worn distributor bushing. Some degree of S curve is due to clearances and tolerances, however. In general, a variation of about 2° is within specifications.

Most mechanical distributor troubles fall into these three categories: worn cam lobes, off-center breaker cam, and timing advance or distributor drive problems.

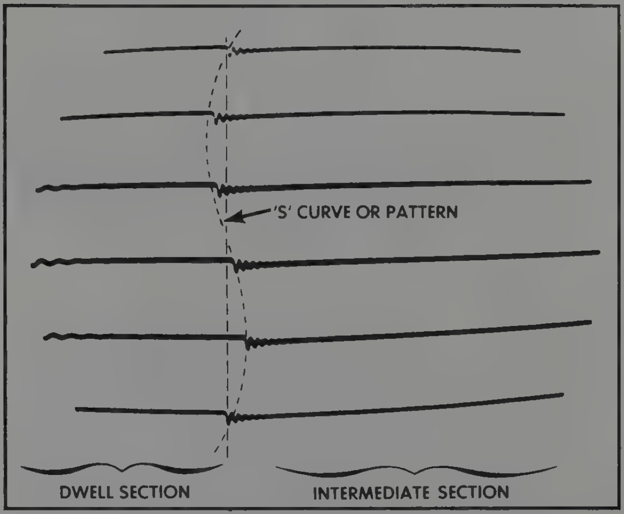


Figure 14-51. This raster display pattern shows an S-curve (or S-pattern) at the breaker points closed signal. (Courtesy of Chevrolet Motor Division, General Motors Corporation)

KEY TERMS

Abnormal display patterns: Oscilloscope display patterns that result from a problem in the firing, intermediate, or dwell sections.

Available voltage: The maximum voltage an ignition system is capable of producing under a given operating condition.

Dwell: The number of degrees the breaker cam rotates while the breaker points are closed.

Firing voltage: The amount of voltage required to produce a spark across the electrodes of a spark plug.

Ignition reserve: The difference between available voltage and firing voltage.

Reverse polarity: A condition caused by a reversed connection at the igntion coil primary terminals, an incorrect ignition coil in the vehicle, or a battery that is connected backwards (reversed).

Snap acceleration: The quick opening and closing of the throttle valve to load the engine for testing.

Spark intensity: The quality (or strength) of spark produced at the spark plug.

SELF-CHECK

1. List the problems that can result from faulty operation of the ignition system.
2. What is the first ignition test to make if the engine cranks but will not start?
3. Explain how to use a spark tester.
4. Describe the appearance of a spark plug taken from an engine with an air-fuel mixture that is too rich.
5. Describe the appearance of a spark plug taken from an engine with an air-fuel mixture that is too lean.
6. Explain how to measure ignition coil secondary resistance.
7. What are common problems associated with the distributor cap and rotor?
8. Explain how to determine whether a spark plug cable is bad?
9. How should the ignition coil primary wires be connected for the correct polarity?
10. What basic instruments can be used to check the operation of an electronic ignition system?
11. List three common problems associated with the primary circuit of a breaker point distributor.
12. Explain how to determine whether a condenser is grounded internally?
13. What is the relationship between dwell and breaker point opening?
14. How is available voltage measured with an oscilloscope?
15. List some of the ignition system components that may be tested with an oscilloscope.

DISCUSSION TOPICS AND ACTIVITIES

1. Use an ignition system simulator and an oscilloscope to program ignition problems into the oscilloscope display patterns. Do the abnormal patterns match those shown in the shop oscilloscope instruction manual?
2. Use graph paper to sketch and label all the abnormal scope patterns. Check your patterns against those in the shop oscilloscope instruction manual.

CERTIFICATION PRACTICE

1. An oscilloscope display pattern for an engine is "upside down" (below the base line). Mechanic A says that this is an indication of reversed polarity. Mechanic B says that this is a normal indication with electronic ignition systems. Who is correct?
   A. Mechanic A
   B. Mechanic B
   C. Both A and B
   D. Neither A nor B
2. When the oscillations in the intermediate section diminish to zero rapidly, it is an indication of a:
   A. Shorted coil
   B. Leaky condenser
   C. Both A and B
   D. Neither A nor B
3. The distance from the breaker points closing signal to the breaker points opening signal on the oscilloscope screen is:
   A. Measured in degrees
   B. Dwell
   C. Both A and B
   D. Neither A nor B
4. When the breaker points closing signal varies for each cylinder, it is an indication of a:
   A. Bent distributor shaft
   B. Worn distributor bushing
   C. Worn breaker cam
   D. Any of the above
5. An ohmmeter connected across the two primary winding terminals of an ignition coil will show an infinite reading. Mechanic A says this is a proper indication. Mechanic B says the primary winding is open. Who is correct?
   A. Mechanic A
   B. Mechanic B
   C. Both A and B
   D. Neither A nor B

ANSWERS

1:A, 2:C, 3:C, 4:D, 5:B

Unit 15

SERVICING THE IGNITION SYSTEM

When troubleshooting procedures indicate a problem with an ignition system component, the component must be serviced or replaced. Some parts, however, such as spark plugs and breaker points, are serviced every time a tune-up is performed. This unit describes procedures that are commonly performed on the ignition system.

DEVELOPING JOB COMPETENCIES

When you finish reading and studying this unit, you should be able to:

- Remove, gap, and replace a set of spark plugs.
- Remove and replace spark plug cables.
- Remove and replace the rotor and distributor cap.
- Remove and replace the distributor and time the engine.
- Remove, replace, and adjust the breaker points and condenser.
- Test the vacuum and centrifugal advance mechanisms or systems.

REMOVAL AND REPLACEMENT OF SPARK PLUGS

A spark plug fires when a spark jumps the air gap between the electrodes and ignites the air-fuel mixture. Whenever the spark cannot jump this air gap, the spark plug is said to misfire. Misfiring occurs when the amount of voltage needed to jump the air gap is greater than the ignition system can provide. The heat, gases, and electron flow begin to deteriorate the electrode surfaces immediately after the spark plug is put into service. Electrode wear eventually widens the air gap to the point that the ignition system cannot provide enough voltage to jump the gap. A build-up of carbon on the firing end of the spark plug may provide an alternate path or circuit for current flow and thus prevent normal ignition.

To remove a spark plug, carefully remove the spark plug cable by pulling on the boot and not on the cable (Figure 15-1). *NOTE: Mark or position the spark plug cables so that they will not get mixed up.*

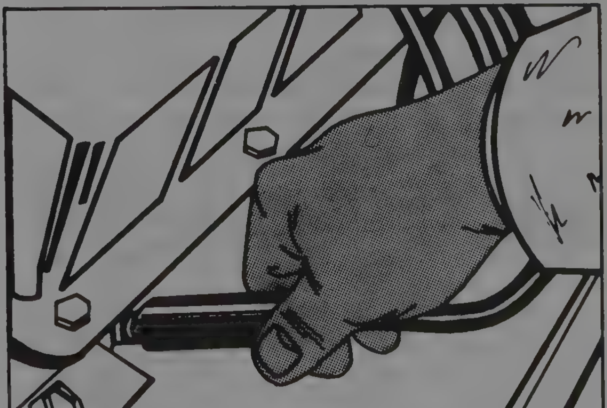


Figure 15-1. Romove the spark plug cable by pulling carefully on the boot.

Select the correct size *spark plug socket* for the *spark plug* (Figure 15-2). Clean the area around the base of the spark plug to prevent dirt from entering the combustion chamber. Place the spark plug socket over the spark plug as shown in Figure 15-3. If the socket is not down all the way, the spark plug could be damaged. After normal service life, a spark plug may be difficult to loosen. Allowing the engine to cool will help in spark plug removal. Also, penetrating oil may help. Apply steady pressure with a *ratchet* until the spark plug loosens.

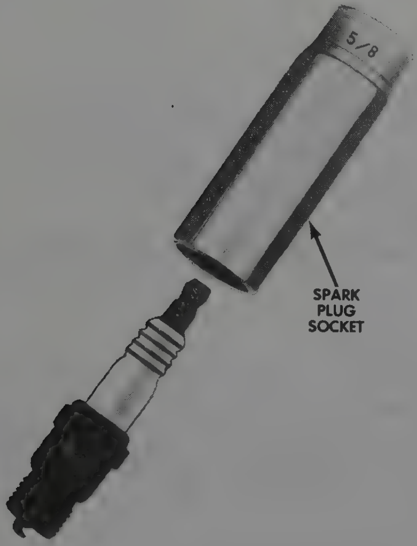


Figure 15-2. Select the correct size spark plug socket for removing the spark plug. (Courtesy of Chevrolet Motor Division, General Motors Corporation)

Since the condition of each spark plug tells something about the cylinder from which it was removed, it is a good idea to keep them in order by placing them in a **spark plug holder** (Figure 15-4). The terminal ends of the spark plugs are placed down so that they can be inspected without being removed from the spark plug holder.

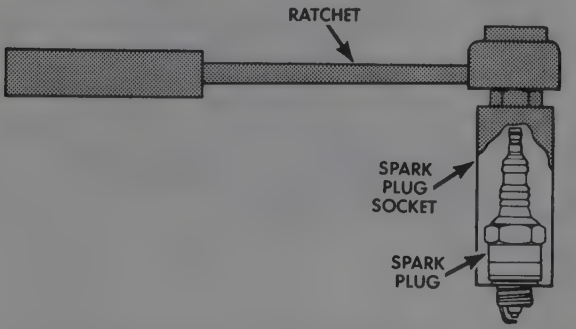


Figure 15-3. The spark plug socket must fit all the way over the spark plug to prevent damage to the spark plug.

Inspect both ends of the insulator, the electrodes, the gasket, and the shell of the plug. The appearance of these components reveals how efficiently the engine has been operating and how suitable the spark plug is for the type of operation. Frequently, the same type of spark plug in two engines of the same make and model will have a different appearance. The difference in appearance may be caused by differences in the condition of the engine, the kind of fuel used, and the condition under which the engine is operated. A spark plug analysis chart (see Unit 14) helps in determining engine condition.

After removing the spark plug, examine the spark plug gasket. The gasket performs two important jobs. First, it conducts away much of the heat absorbed by the spark plug insulator tip. Second, it maintains a tight seal between the spark plug and its seat in the cylinder head. If the spark plug gasket is not properly seated, leaking combustion gases will cause overheating of the spark plug.

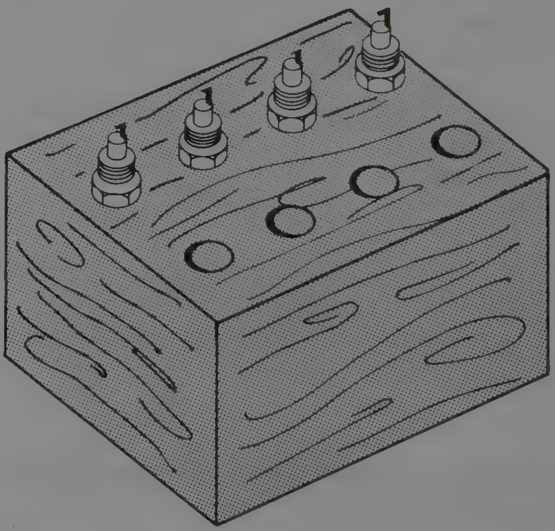


Figure 15-4. Typical spark plug holder with spark plugs from a four-cylinder engine.

If the gasket is flattened too much, the spark plug shell may be distorted or cracked, and the spark plug gap or air gap may be changed by the excessive torque. Figure 15-5 shows a spark plug *gasket* before installation (new), after

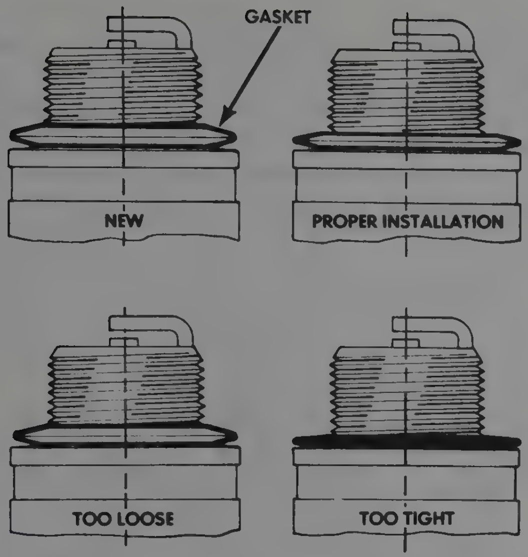


Figure 15-5. Comparison of spark plug gasket condition when new (before installation) and after installation with different amounts of torque. (Courtesy of Chevrolet Motor Division, General Motors Corporation)

proper installation, after too loose an installation, and after too tight an installation.

NOTE: A new gasket must be used each time a spark plug is installed in an engine.

Many engines now use a spark plug with a special tapered seat. This type of spark plug does not require a gasket.

When installing new spark plugs, check the codes on the spark plugs to make sure that they are the ones specified for the engine. Look up the specifications for air gap. Several types of wire feeler gages are available. They have a selection of *feeler wires* ground to specific diameters. The feeler wires may be U-shaped or L-shaped. They usually have a bending attachment for adjusting the air gap (Figure 15-6).

Select the correct size *feeler wire* and place it between the ground and center electrodes (Figure 15-7). If the feeler wire will not fit between the electrodes, the air gap is too small. If it fits too loosely, the air gap is too large. A slight drag is felt when a proper fit is achieved.

To adjust the air gap, select the correct size *bending attachment* and carefully bend the *ground electrode* closer or further away from the *center electrode* (Figure 15-8). Recheck the air gap and adjust as necessary.

CAUTION: Never bend the center electrode sideways. This could crack or break the insulator tip or damage the electrode. Do not use pliers for gapping.

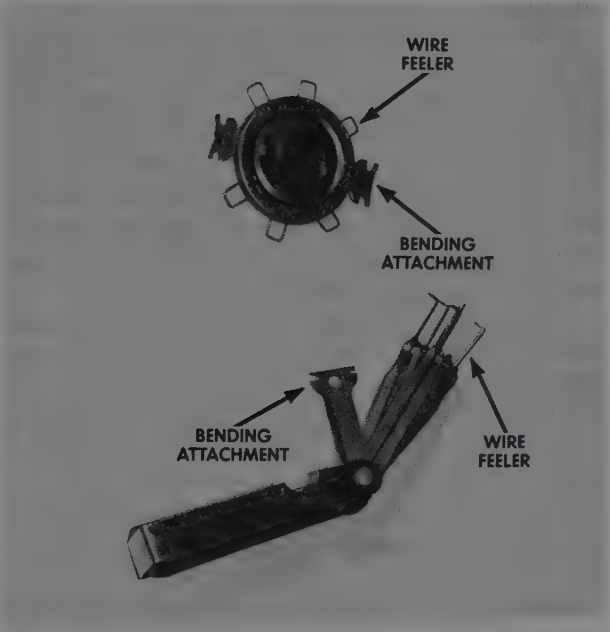


Figure 15-6. Typical wire feeler gages with bending attachments.

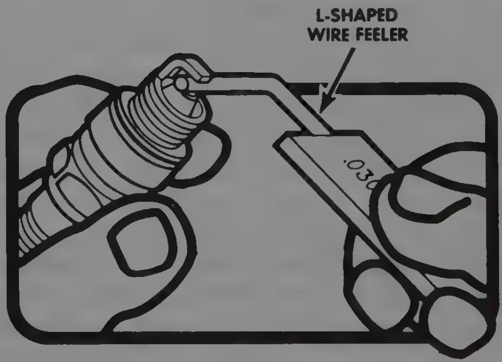


Figure 15-7. The feeler wire is placed between the ground and center electrodes to check the air gap. (Courtesy of Sun Electric Corporation)

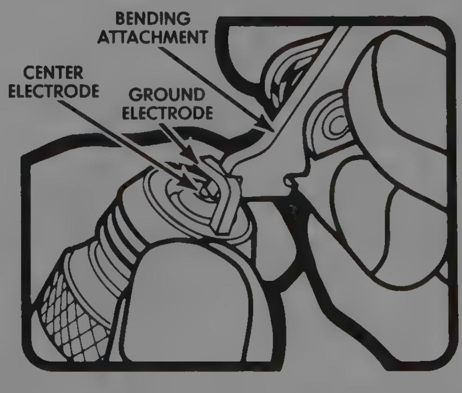


Figure 15-8. The air gap is adjusted by bending the ground electrode. (Courtesy of Sun Electric Corporation)

Install the new spark plug finger-tight. Use a torque wrench to tighten each spark plug. (Look up torque specifications in the service manual.) Replace the spark plug cables by pushing the boots firmly in place over the spark plugs.

REMOVAL AND REPLACEMENT OF SPARK PLUG CABLES

If, on testing, spark plug cables have too high a resistance, or if a visual inspection shows insulation deterioration, the cables must be replaced. To avoid mixing up the spark plug cables, remove them one at a time. Spark plug cables are normally supplied in sets that are precut, with all the terminals and boots installed.

WARNING: Make sure the ignition switch is off when removing spark plug cables to avoid an electrical shock.

Some electronic ignition systems require silicone grease inside each spark plug cable. The grease is used to prevent the entrance of moisture. Apply this grease before installing the new spark plug cable.

Check each cable's location in relationship to its spark plug and its position on the distributor cap to ensure correct installation. Remove the spark plug cable from the spark plug by pulling firmly at the base of the spark plug boot. Remove the spark plug cable from the distributor cap by pulling firmly on the rubber boot.

Find the replacement cable that is closest in length to the old one. Install the new spark plug cable with the *sealing nipple* over the *distributor cap tower* by pushing lightly on the large diameter of the sealing nipple (Figure 15-9). Also, squeeze or pinch the sealing nipple to release any trapped air between the nipple and the tower. Be sure that the new cable is properly seated on the tower. Place the boot over the spark terminal and push firmly into place. Repeat this procedure for each spark plug cable. Also, use the same procedure to install the secondary cable or stinger in the ignition coil (Figure 15-10).

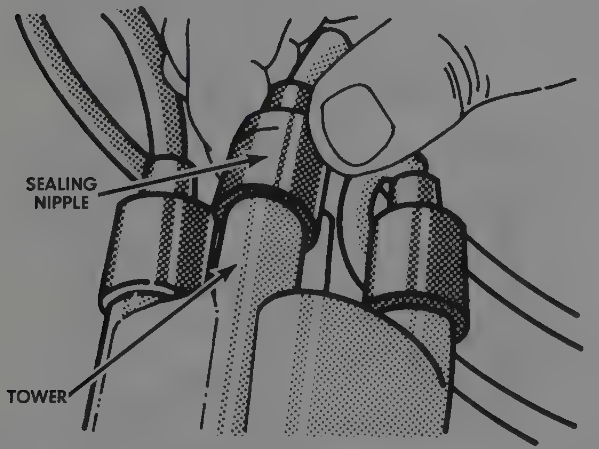


Figure 15-9. Installing the spark plug cable on the distributor cap. (Courtesy of Chrysler Corporation)

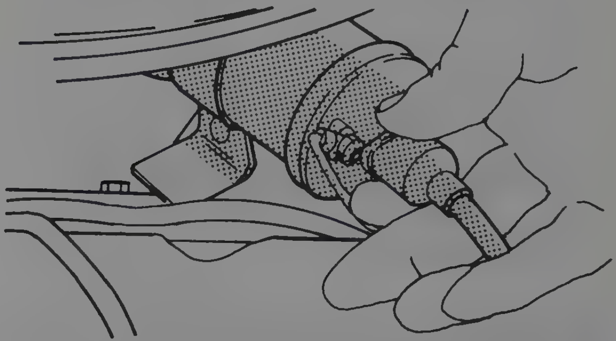


Figure 15-10. Installing the secondary cable or stinger in the ignition coil. (Courtesy of Chrysler Corporation)

REMOVAL AND REPLACEMENT OF DISTRIBUTOR CAP AND ROTOR

If testing or visual inspection indicates a problem with the distributor cap or rotor, they must be replaced. **WARNING: Make sure the ignition switch is off while replacing the distributor cap or rotor to avoid an electrical shock.**

To remove a distributor cap with *spring-loaded screw clamps* from the distributor, press down on the screw clamp and turn it in either direction. To remove the distributor cap from a distributor with *spring clasps*, place a screwdriver between the spring clasp and the distributor housing and pry outward. **CAUTION: Do not apply screwdriver pressure to the distributor cap itself as it might crack.**

To replace a defective distributor cap, place the old and the new one side by side in the same relative position, noting the *locating lugs* or *slots* (Figure 15-11). Remove one spark plug cable at a time from the old distributor cap and place it in the same position on the new distributor cap. It must first be pushed into place on the tower and then the sealing nipple placed securely over the tower.

NOTE: On vehicles that require silicone grease in the distributor cap, do not clean the metal inserts with solvent. As silicone ages, it

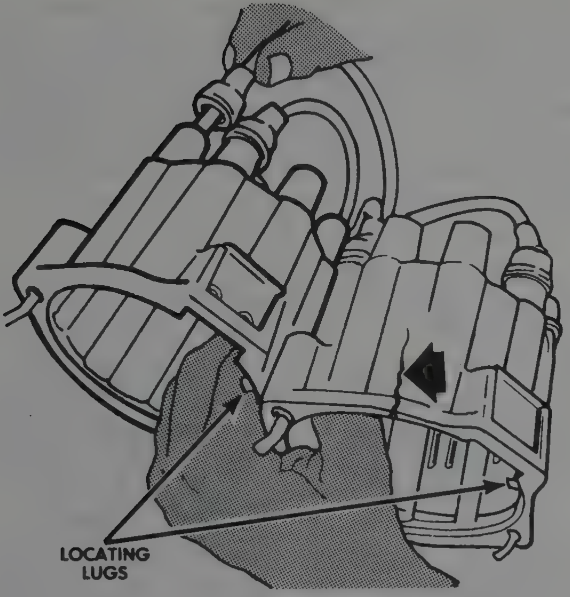


Figure 15-11. Hold the new distributor cap and old (cracked) distributor cap side by side to avoid mixing up the spark plug cables. (Courtesy of Delco Remy, Division of General Motors Corporation)

may look like contaminant, but this is normal and causes no performance loss.

When the distributor cap is removed, the rotor may be inspected and replaced if necessary. On the type of distributor shown in Figure 15-12, the *rotor* is released by removing the mounting screws. Most types of rotors are removed by pulling up on the *rotor* (Figure 15-13). To install this type of rotor, push it down over the distributor shaft (Figure 15-14).

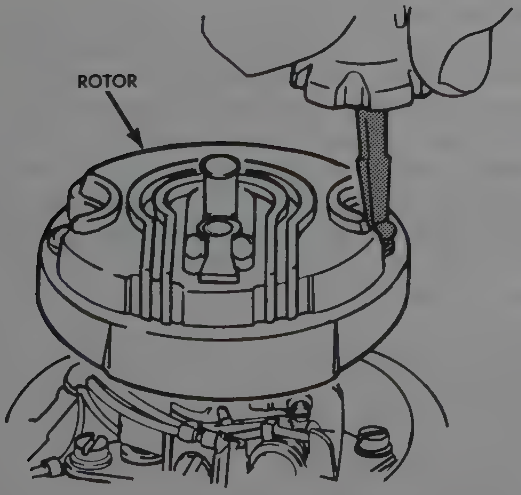


Figure 15-12. This type of rotor is held in place by screws. (Courtesy of Delco Remy, Division of General Motors Corporation)

CAUTION: Do not press on the rotor contact strip. Make sure the rotor is pushed all the way down. The blades of rotors used on some electronic ignition systems must be greased with silicone grease.

After the rotor has been serviced, the distributor cap may be reinstalled. To ensure proper positioning of the cap on the distributor housing, most distributor caps have a *locating lug* (Figure

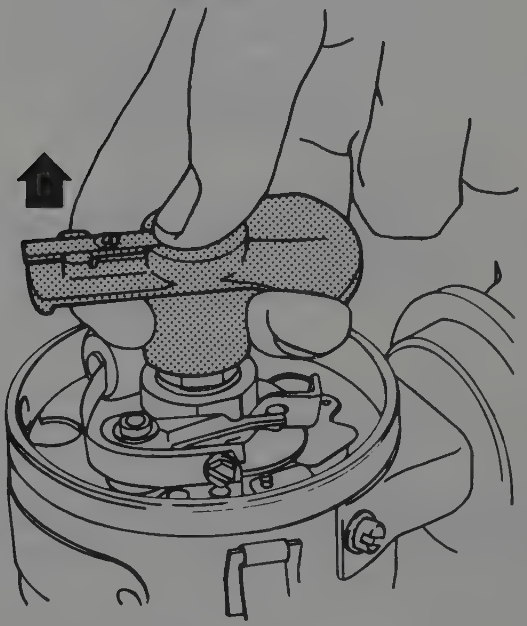


Figure 15-13. This type of rotor is removed by pulling it off the distributor shaft. (Courtesy of Delco Remy, Division of General Motors Corporation)

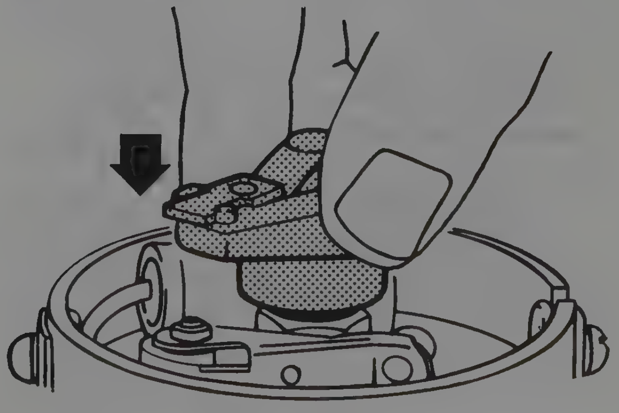


Figure 15-14. Install the rotor by pushing it onto the distributor shaft. (Courtesy of Delco Remy, Division of General Motors Corporation)

15-15) that mates with a corresponding *slot* in the distributor housing. Some distributor caps have either a *locating lug* that fits into the slot of a *spring clasp*, or a *groove* or *slot* that fits over a *boss* on the distributor (Figure 15-16).

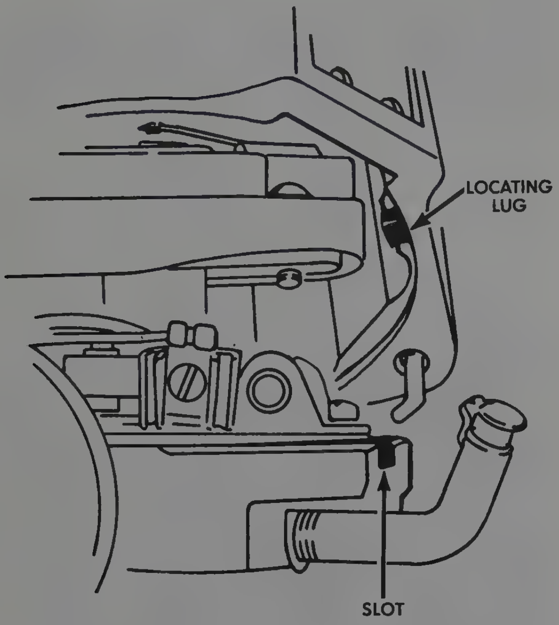


Figure 15-15. The locating lug on the distributor cap must fit into the slot in the distributor. (Courtesy of Delco Remy, Division of General Motors Corporation)

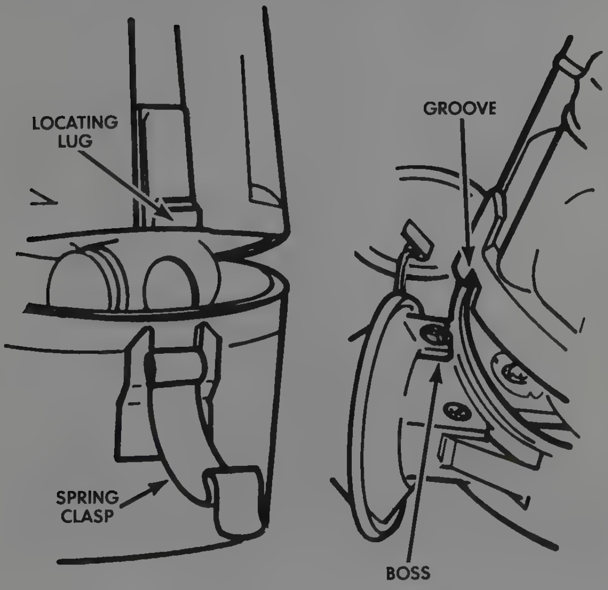


Figure 15-16. Different types of distributor cap positioning mechanisms. (Courtesy of Delco Remy, Division of General Motors Corporation)

After replacing the distributor cap, secure it to the distributor either by pressing on the center of the *spring clasp* to force it over the locating lugs, or by using a screwdriver to press down on the *screw clamp*, turning until it is under the slot on the bottom of the distributor (Figure 15-17).

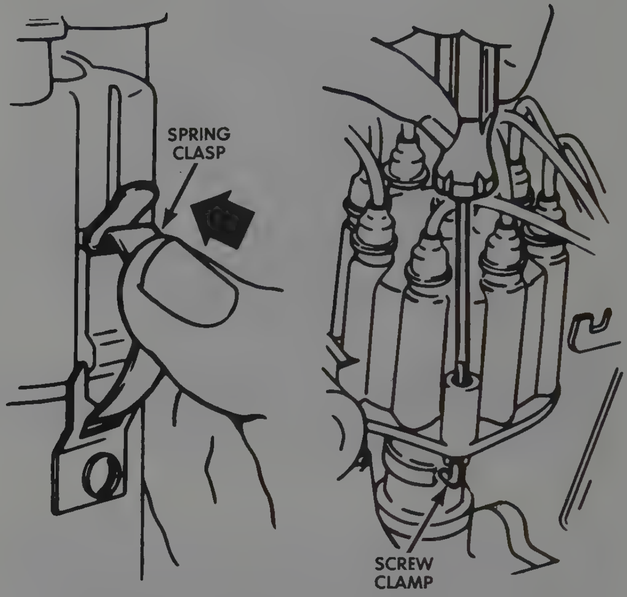


Figure 15-17. Securing the distributor cap. (Courtesy of Delco Remy, Division of General Motors Corporation)

REMOVAL AND REPLACEMENT OF DISTRIBUTOR

Most service procedures are performed on the distributor more easily if the distributor is removed from the engine. For example, it is easier to service breaker points and advance mechanisms and to overhaul the distributor when it is removed from the engine. **WARNING: Always turn the engine off when removing the distributor to avoid an electrical shock.**

The first step in removing the distributor is to remove the distributor cap as described under the heading, “Removal and Replacement of Distributor Cap and Rotor,” earlier in this unit. Place the cap clear of the immediate work area. Disconnect the distributor primary lead from the ignition coil terminal or electronic control unit. Disconnect any vacuum lines attached to the distributor. Scribe a *realignment mark* on the distributor housing and the engine in line with the *rotor blade* (Figure 15-18). Remove the distributor hold-down bolt and clamp, and lift the distributor from the engine.

CAUTION: Do not rotate (crank) the engine with the distributor removed, as the ignition timing will be disturbed.

To reinstall the distributor, turn the rotor about one-eighth of a turn (in the direction it normally rotates in the engine) past the realignment mark on the distributor housing to position the rotor. This will provide for proper meshing of the distributor and cam gears. Push the distributor down into the engine block with the distributor housing in a normal installed position. It may be necessary to move the rotor slightly to start the gears to mesh. However, the rotor blade should align with the realignment mark on the distributor housing when in place. Move the distributor housing so that the realignment marks on the engine and housing are aligned.

Secure the distributor with the hold-down bolt and clamp. Connect the primary lead to the ignition coil terminal or to the electronic control unit (whichever was disconnected) and install the distributor cap. Adjust the basic timing to specifications as described in Unit 13.

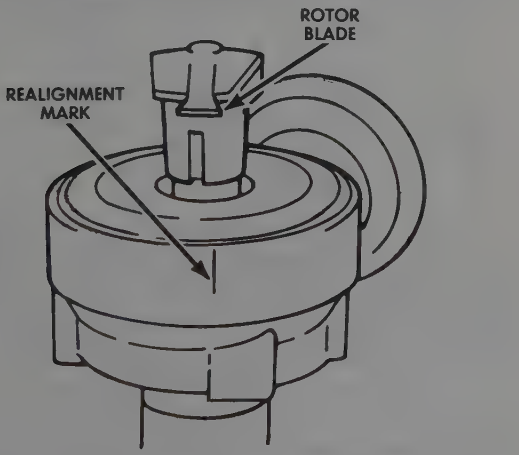


Figure 15-18. A scribed realignment mark on the distributor housing helps to correctly position the distributor in the engine, which has a corresponding scribed realignment mark. (Courtesy of American Motors Corporation)

Replacing Distributor if Engine Cranked

If the engine has been cranked with the distributor removed, the distributor must be retimed to the engine before the distributor is installed. To retime the distributor, first locate the No. 1 cylinder piston in the firing position with both intake and exhaust valves closed. This can be done by removing the No. 1 spark plug and covering the spark plug hole with a finger while an assistant cranks the engine until compression is felt in the cylinder. Continue cranking the engine until the timing marks on the pulley, damper, or flywheel align with the top dead center (TDC) mark. Place and secure the distributor in the engine block in the normal installed position as described earlier in this unit. Also, reconnect the vacuum lines and electrical leads as described earlier. Replace the distributor cap. Check to see that the rotor lines up with the metal insert (terminal) for the No. 1 spark plug. If the rotor does not line up, turn the distributor until it does.

REMOVAL AND REPLACEMENT OF BREAKER POINTS AND CONDENSER

Breaker Points

Breaker point distributors should have their breaker points replaced at each tune-up. Breaker points may be replaced while the distributor is in the engine, but most tune-up technicians prefer to remove the distributor and service the breaker points while the distributor is in a *distributor tester*. (A distributor tester is discussed later in this unit.)

Removal. To remove the breaker points, note the wire lead arrangements so that they can be properly reinstalled without interfering with the breaker cam, the breaker points, or the rotor. Then loosen the mounting screw and remove the *primary leads* from the terminal (Figure 15-19). Next, loosen the *mounting*

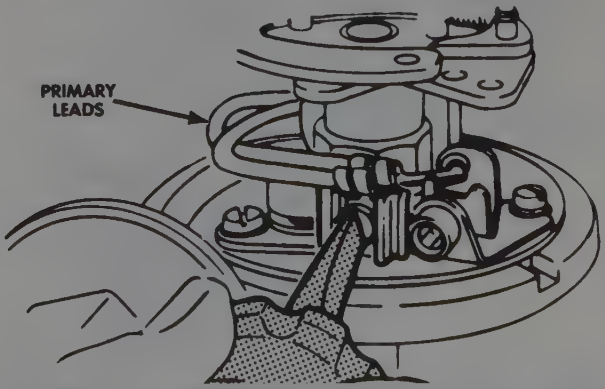


Figure 15-19. The primary leads must be disconnected for the breaker points to be removed. (Courtesy of Delco Remy, Division of General Motors Corporation)

screws (Figure 15-20) that hold the breaker points to the *breaker plate. NOTE: It is not necessary to completely remove the mounting screws.*

Remove the breaker points. Be sure to note the *locating hole* in the base of the breaker point set that fits over the *locating protrusion* on the breaker plate (Figure 15-21).

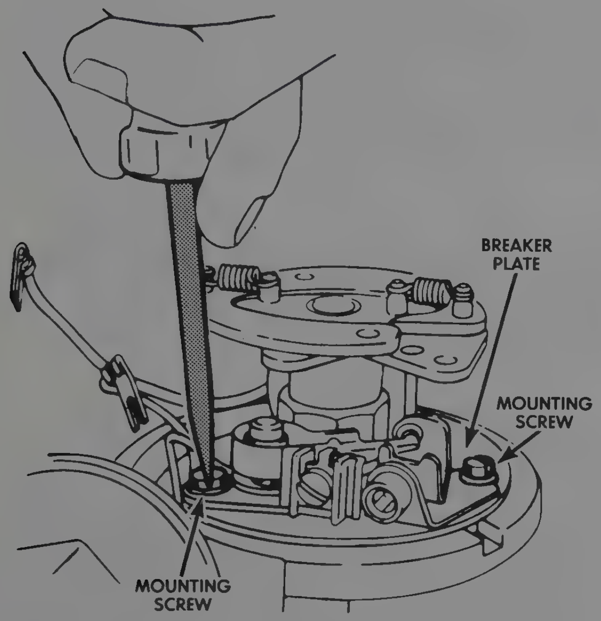


Figure 15-20. To remove the breaker points, loosen the mounting screws. (Courtesy of Delco Remy, Division of General Motors Corporation)

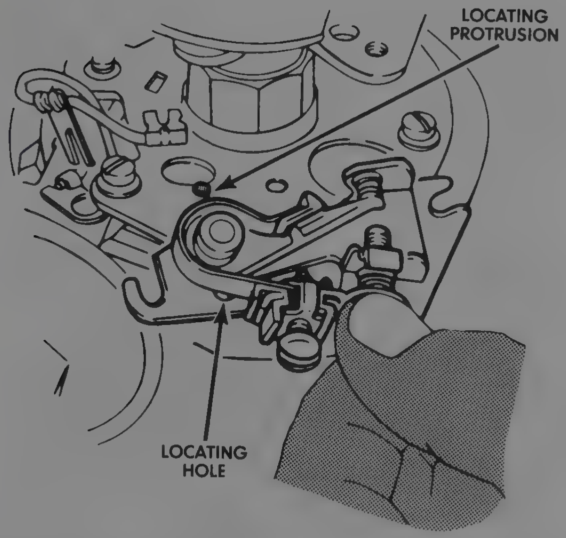


Figure 15-21. The locating hole and locating protrusion help to ensure proper installation of the breaker point set (see arrows). (Courtesy of Delco Remy, Division of General Motors Corporation)

With some breaker points, the primary lead terminal nut must be loosened before the breaker points can be removed (Figure 15-22). Once again, the wire lead arrangement must be noted. Remove the mounting screw that holds the base of the breaker point set to the *breaker plate* (Figure 15-23). Lift up on the breaker point set to remove it from the *eccentric adjusting screw* (located behind the *movable breaker point arm*) and the *pivot post.*

NOTE: On distributors that contain two sets of breaker points, it is imperative to note the wire lead arrangements so that they are not accidently reversed upon reassembly.

CAUTION: Before either a new breaker point set or a new condenser is installed in the distributor, the breaker plate should be cleaned of any dirt, grease, or foreign material.

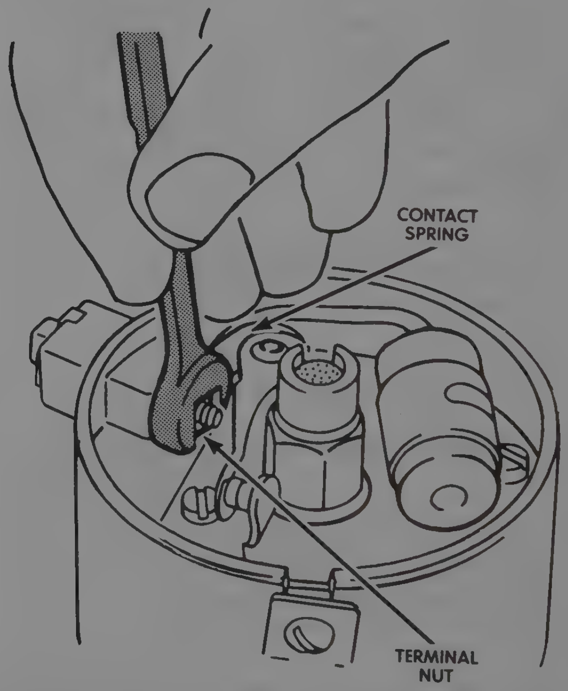


Figure 15-22. Loosen the primary lead terminal nut to release the contact spring so that the breaker points can be removed. (Courtesy of Delco Remy, Division of General Motors Corporation)

The breaker cam should receive a light coating of grease, per specifications, on its surface prior to breaker point installation. The amount of grease applied should be kept to a minimum to prevent the excess grease from being thrown off at high speeds or high temperatures.

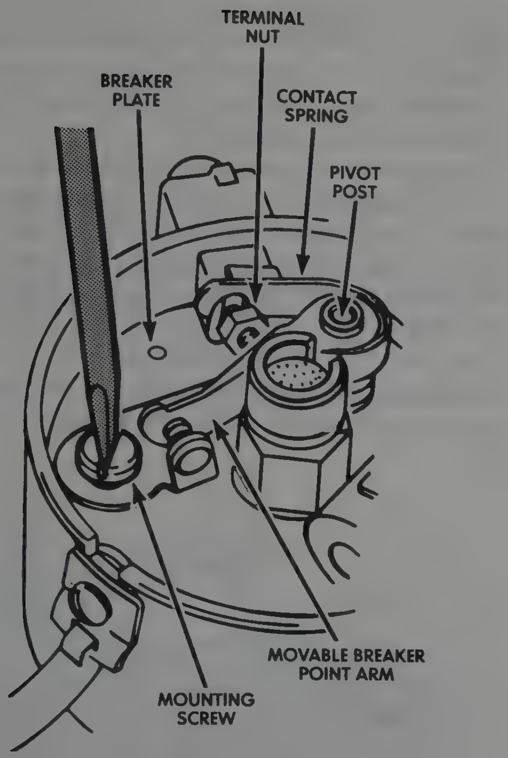


Figure 15-23. Remove the breaker point mounting screw. (Courtesy of Delco Remy, Division of General Motors Corporation)

Installation. To install a new breaker point set, place it over the pivot post and attach it to the breaker plate with the mounting screws (Figure 15-24). *NOTE: Do not tighten securely until after the breaker point setting is made.*

Carefully replace all condenser and primary leads. (The condenser is covered in detail later in this unit.)

Adjustment. After installing a set of new breaker points, it is necessary to set the breaker point opening for correct dwell. If the distributor is in the engine, have an assistant crank the engine until the *rubbing block* is on the high point of a *cam lobe* (Figure 15-25). If the distributor is out of the engine, turn the distributor shaft to fully open the breaker points. This position is the maximum breaker point opening. Breaker point opening is then adjusted to the correct specification by moving the stationary breaker point. A *flat* or *wire feeler gage* of the correct thick-

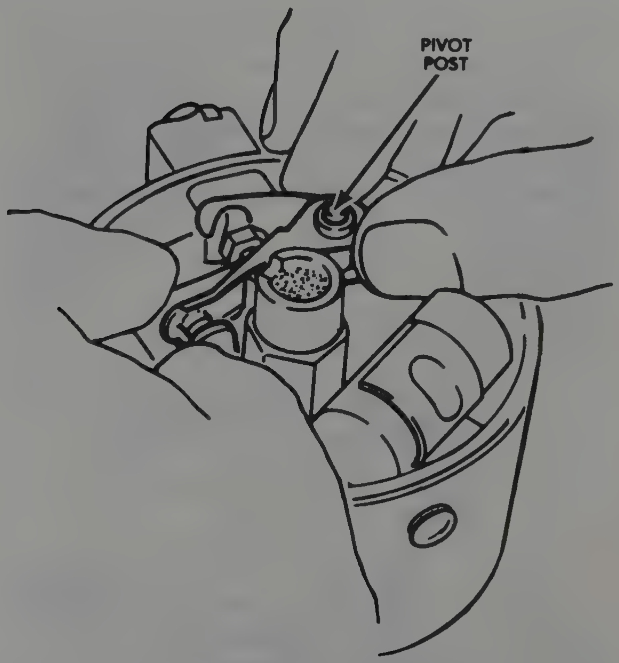


Figure 15-24. Install the new breaker point set over the pivot post. (Courtesy of Delco Remy, Division of General Motors Corporation)

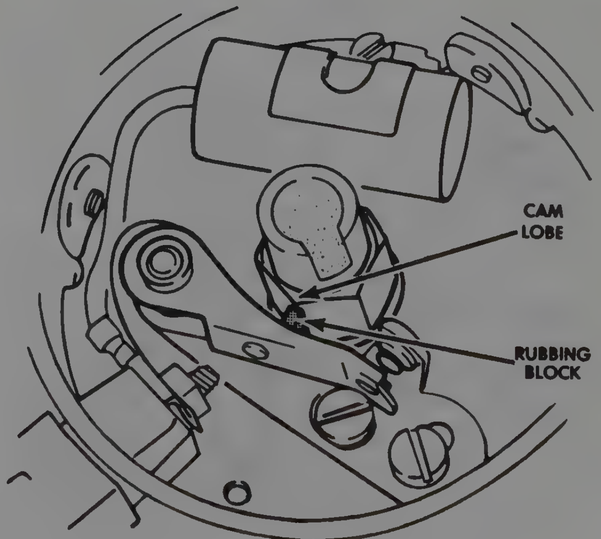


Figure 15-25. The rubbing block must be on the high point of the cam lobe when breaker point opening is set. (Courtesy of Delco Remy, Division of General Motors Corporation)

ness is inserted (Figure 15-26) between the breaker points to obtain the correct setting. For the breaker points shown in Figure 15-26, an *eccentric screw* is used to move the *stationary breaker point* for adjustments.

On some breaker points, a screwdriver (placed in a *notch* or *slot*) is used to adjust the stationary breaker point position after the breaker point *mounting screws* are loosened (Figure 15-27). The mounting screws must be tightened securely after the correct breaker point opening is obtained.

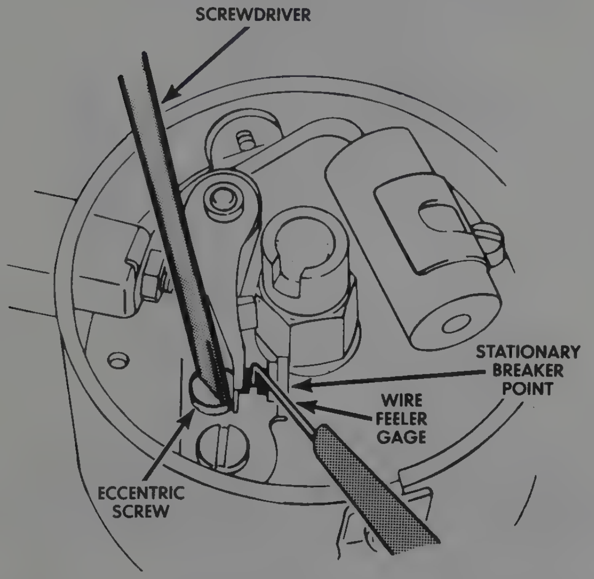


Figure 15-26. On this distributor, an eccentric screw is used to adjust the position of the stationary breaker point. (Courtesy of Delco Remy, Division of General Motors Corporation)

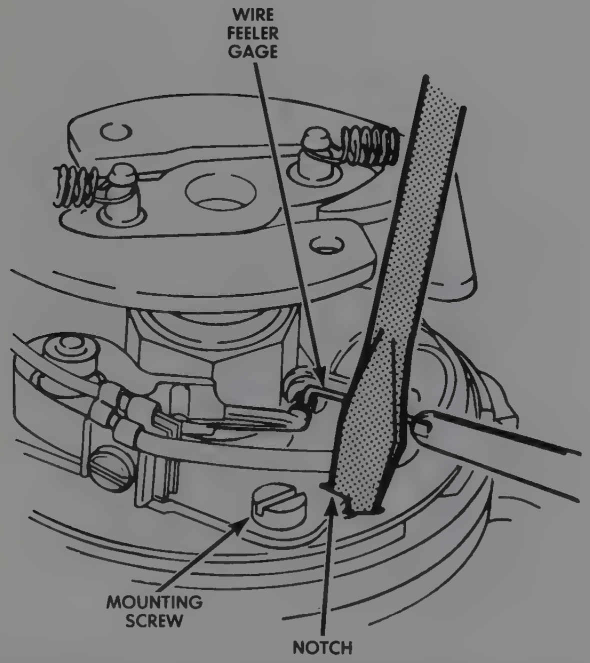


Figure 15-27. On this distributor, a screwdriver notch or slot is used to adjust the breaker point gap. (Courtesy of Delco Remy, Division of General Motors Corporation)

Some breaker point sets allow for adjustment of the breaker point opening or gap externally. This is accomplished with an Allen wrench which engages an *adjustment screw* (Figure 15-28) through a window or access door in the distributor cap.

NOTE: On dual point distributors, the breaker point opening of each set must be checked and set before the vehicle is ready for operation.

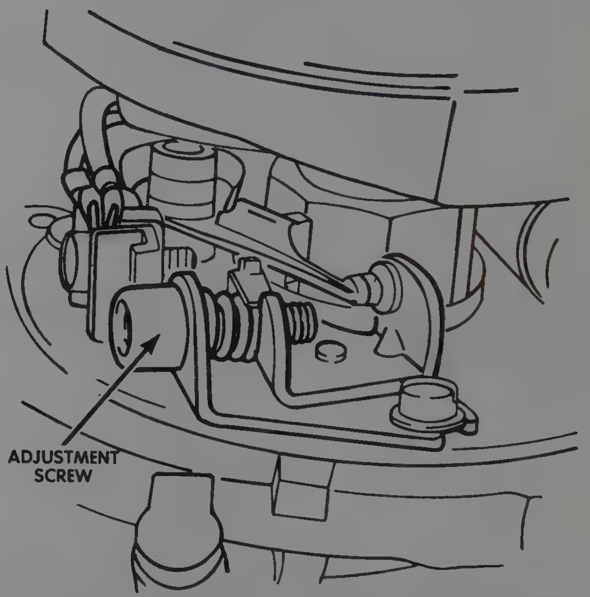


Figure 15-28. On this distributor, an Allen wrench is used to thread the adjustment screw in or out to set the breaker point gap. (Courtesy of Delco Remy, Division of General Motors Corporation)

After the breaker points are installed and gapped, their alignment and spring tension must be checked. Proper alignment is important to breaker point service life. If the contact surfaces of the breaker points are not aligned laterally (Figure 15-29), their ability to dissipate heat is reduced. This causes excessive breaker point wear and burning. The breaker points are aligned laterally by bending the stationary breaker point support, or arm, with a special alignment tool shown in Figure 15-30. **CAUTION: The movable breaker point arm must never be bent, or it could be broken.**

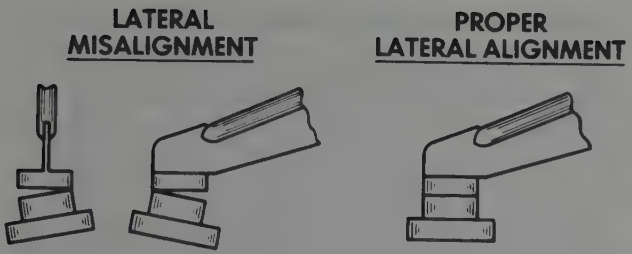


Figure 15-29. The breaker points must be aligned properly to attain a normal service life. (Courtesy of Chevrolet Motor Division, General Motors Corporation)

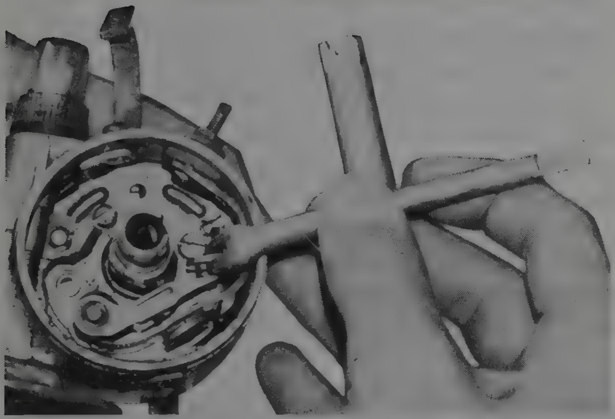


Figure 15-30. Breaker points are aligned by bending the stationary breaker point arm with a special alignment tool.

Proper breaker point spring tension is an important factor in obtaining normal breaker point service life and maintaining full ignition system efficiency throughout the speed range of the engine. If the spring tension is excessive, rapid wear of the rubbing block, breaker cam, and breaker points will result. Insufficient spring tension also may allow the breaker points to bounce at high engine RPM. This in turn may result in breaker point arcing and burning.

Spring tension is measured with a **spring tension gage** (Figure 15-31). With the breaker points closed, hook the spring tension gage to the movable breaker point arm at the point of contact and exert a pulling force at 90° to the breaker point arm. Take a reading just as the breaker points open. If the reading is not within the limits of the specifications in the manufacturer's service literature, replace the breaker points.

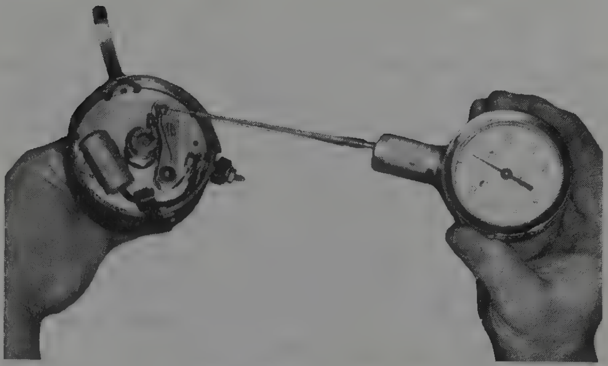


Figure 15-31. A spring tension gage is used to measure breaker point spring tension.

Condensers

The ignition condenser is normally tested and replaced along with the breaker points. If the condenser is functioning properly, the breaker points will have a long service life. When the breaker points are inspected, they should be examined for evidence of pitting. Pitting results from an out-of-balance condition in the ignition system that causes transfer of tungsten from one breaker point to the other. As a result, a tip builds up on one point while a pit forms in the other.

Condensers are tested on a *condenser tester*, which is normally included on most distributor testers and oscilloscope consoles. The condenser is tested for:

1. Series resistance (the amount of resistance the condenser provides in the primary circuit), which affects ignition coil output.
2. Leakage, which determines if the condenser insulation can withstand the demands of the ignition system.
3. Capacity, which affects point arcing and pitting.

The manufacturer's instruction manual should be followed when performing these tests. If a condenser fails any one of the tests, it must be replaced. A new condenser should be tested prior to installation to make sure it is in good condition.

To remove the condenser, first remove the wire leads from the primary terminal and loosen the mounting screw that holds the condenser bracket to the breaker plate. Note the locating tangs and locating holes on the condenser bracket (Figure 15-32). They are used to properly install the condenser. Some condensers may have only one locating hole in the mounting bracket. To install the replacement condenser, reverse the disassembly procedure.

After the new breaker points and the new condenser are installed, the dwell should be checked and adjusted to specifications. Be sure that the breaker points and condenser do not physically interfere with breaker plate movement. After checking and adjusting dwell, set the basic timing to specifications.

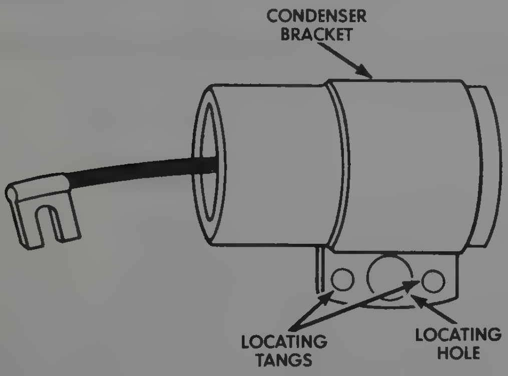


Figure 15-32. The locating tangs and locating hole in the condenser bracket are used to properly install the condenser.

SERVICING ADVANCE SYSTEMS

The centrifugal (speed) and vacuum (load) advance mechanisms should be checked and adjusted, if necessary, during a tune-up. This can be accomplished with the distributor mounted on a distributor tester.

NOTE: Some distributors have provisions for adjusting both centrifugal and vacuum advance mechanisms. Most distributors, however, require that the parts of the centrifugal or vacuum advance mechanisms be replaced to correct a problem. Always check the procedure in the manufacturer's service manual.

Using the Distributor Tester

The distributor tester can be used for a number of service operations. When a distributor tester is available, the usual practice during a tune-up is to remove the distributor from the vehicle and install it on the distributor tester. A clamp arrangement allows the distributor housing to be held securely while the shaft is positioned in a motor-driven chuck. The distributor tester motor allows the operator to spin the distributor shaft just as it spins in the engine (Figure 15-33).

SUN
Sun 504
UTOR TESTER

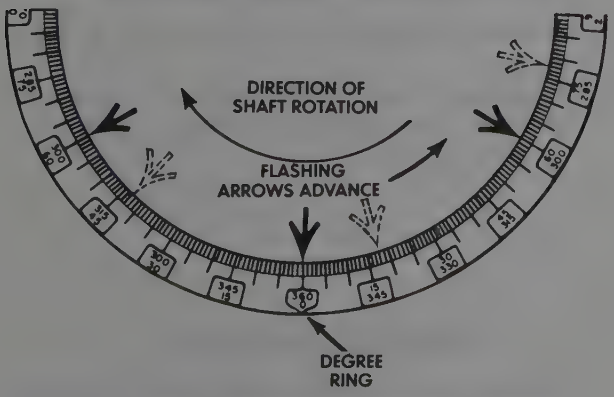
Figure 15-33. The tune-up technician tests distributor operation as the distributor tester spins the distributor shaft.

While the distributor shaft is rotating, a number of tests and adjustments can be made.

Breaker points and condenser replacement are easily accomplished with the distributor mounted in the distributor tester. Many distributor testers also include a condenser meter or tester for testing the condenser. After the breaker points have been installed, the distributor shaft can be driven at engine speed to give the rubbing block an initial break-in period. A dwell meter on the distributor tester can then be used to accurately set the dwell. An operator can easily adjust the breaker point gap while the distributor is being driven and while observing the dwell meter. The distributor tester's instruction manual provides procedures to check breaker point alignment, dwell variation, cam lobe accuracy, and breaker point and primary lead resistance.

Servicing the Centrifugal Advance Mechanism

With the distributor correctly mounted on the distributor tester, the centrifugal advance mechanism may be tested to determine if it conforms to the manufacturer's specifications. A defective centrifugal advance mechanism results in poor performance as well as abnormal combustion and possible engine damage. The distributor tester has a movable round disc with degree increments called a *degree ring* (Figure 15-34). Primary current through the breaker points activates a series of *arrows* that flash next to the degree ring each time the breaker points separate or open.



NOTE: "GHOSTED" ARROWS IN THIS ILLUSTRATION SHOW AMOUNT OF ADVANCE AFTER RPM IS INCREASED.

Figure 15-34. A degree ring on the distributor tester shows the number of degrees of advance. (Courtesy of Sun Electric Corporation)

At a low distributor shaft RPM, the degree ring is rotated so that an arrow is lined up with the zero on the degree ring. As RPM is increased, the centrifugal advance mechanism causes the breaker points to open earlier, causing the arrows to move in relation to the advance. The amount of advance at any RPM is indicated by the number of degrees that the arrows move on the degree ring. This measurement should be compared to the manufacturer's specifications.

If the advance is excessive, the springs that retain the centrifugal weights may be weak, or the wrong springs may have been installed. If the advance is slow, the centrifugal weights may be sticking. If the advance is insufficient, the springs' tension is excessive.

Servicing the Vacuum Advance Mechanism

The distributor vacuum advance mechanism should also be checked against manufacturer's specifications. A *vacuum motor* located in the distributor tester is connected through a *hose* to the *vacuum diaphragm* on the distributor. At a low distributor RPM, the arrows are lined up with the zero on the degree ring. A *vacuum regulator knob* is used to apply the proper amount of vacuum for each specified check point. Again, movement of the flashing arrows allows the operator to read the amount of advance. This is then compared to manufacturer's specifications.

If the advance is excessive, the vacuum advance mechanism may have a weak diaphragm spring. If the advance is insufficient or is erratic, the diaphragm spring may be too strong, or the distributor plate or linkage may be sticking or binding. Should the vacuum advance mechanism fail to hold a vacuum, the diaphragm could be damaged.

Total Advance

Manufacturers sometimes provide a specification for **total advance.** Total advance is the sum of the degrees of advance from basic timing, speed advance, and load advance. It can be measured with the distributor in the engine or in a distributor tester.

Distributor in the Engine. The engine is operated at a specific RPM and the amount of advance noted with a timing light or magnetic probe. If the total advance is not correct, the two advance systems (speed and load) as well as basic timing must be checked. **CAUTION: Never try to set total advance by moving the distributor.**

Distributor in a Distributor Tester. Total advance must be determined from *degrees of distributor advance*. (Degrees of distributor advance are either centrifugal advance or vacuum advance or both.) The indicator, or degree ring, on most distributor testers is graduated in degrees of advance. Since the distributor turns at half the crankshaft speed, 1° of distributor advance equals 2° of crankshaft advance. If the distributor tester shows 10° of advance, the advance with the distributor in the engine is 20°. The amount of basic advance (the advance associated with basic timing) is not shown on the distributor tester. Therefore, to determine total advance, the tune-up technician must double the reading on the distributor tester and then add the specified amount of basic advance. For example: If the distributor tester shows an advance of 12° and the manufacturer specifies 2° of basic advance, the total advance is 26° (12° x 2° = 24° + 2° = 26°).

KEY TERMS

Spark plug holder: A tray used to hold spark plugs with their terminal ends down. This allows for inspection and comparison.

Spring tension gage: A gage used to measure the spring tension of the movable breaker point arm.

Total advance: The sum of the degrees of advance from basic timing, speed advance, and load advance.

SELF-CHECK

1. Why should a spark plug socket fit all the way over a spark plug?
2. Why should spark plugs be placed in proper order in a spark plug holder after removal?
3. What two methods are used to seal the area between the spark plug and the combustion chamber?
4. Explain how to adjust the air gap on a spark plug.
5. Explain how to replace a distributor cap without mixing up the spark plug cables.
6. Describe two methods of locating the distributor cap on the distributor housing.
7. Explain how to remove and replace a distributor.
8. Why should the engine not be cranked with the distributor removed?
9. How can the distributor be timed to the engine if the engine is cranked with the distributor removed?
10. Describe two methods of adjusting breaker point opening, or gap.
11. In what position should the breaker cam and rubbing block be when breaker point gap is adjusted?
12. Why is it important to properly align breaker points?
13. Explain how to determine total advance.

DISCUSSION TOPICS AND ACTIVITIES

1. Practice timing a distributor on a test engine.
2. Disassemble and reassemble a selection of shop distributors. What design variations do you notice?

CERTIFICATION PRACTICE

1. A spark plug gasket that is not seated properly may cause:
   A. Leaking combustion gases
   B. Overheated spark plug
   C. Both A and B
   D. Neither A nor B

2. When installing a new spark plug, be sure to:
   A. Check the spark plug code
   B. Check and adjust the air gap to specifications
   C. Both A and B
   D. Neither A nor B
3. Total advance is the result of:
   A. Load advance
   B. Speed advance
   C. Basic timing
   D. All of the above
4. Breaker point opening and dwell are adjusted by:
   A. Moving the stationary breaker point
   B. Bending the stationary breaker point
   C. Moving the movable breaker point
   D. Bending the movable breaker point
5. Condensers are tested for:
   A. Series resistance
   B. Leakage
   C. Capacity
   D. All of the above

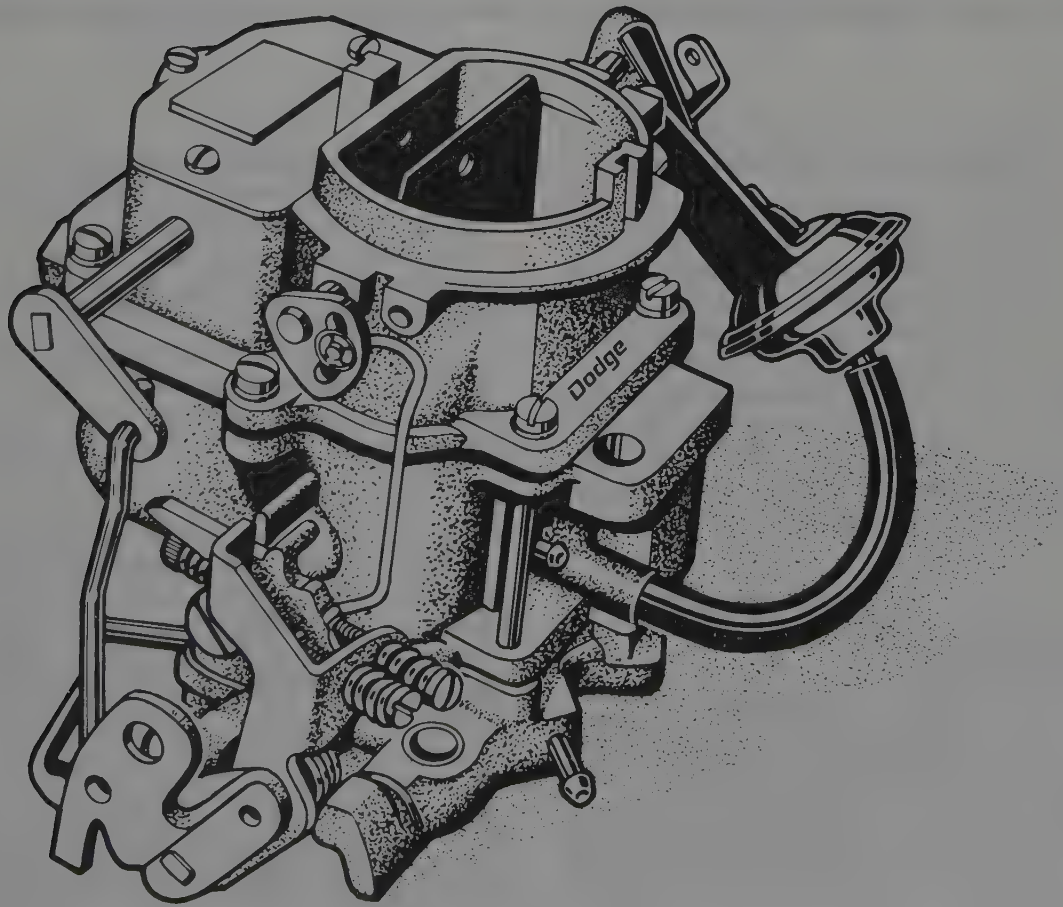
ANSWERS

1:C, 2:C, 3:D, 4:A, 5:D

SECTION V

Fuel System

Unit 16. Fuel System Operation — Carburetion Systems
Unit 17. Fuel System Operation — Electronic Fuel Injection Systems
Unit 18. Troubleshooting the Fuel System
Unit 19. Servicing the Fuel System



Courtesy of Chrysler Corporation

Unit 16 FUEL SYSTEM OPERATION — CARBURETION SYSTEMS

The purpose of the fuel system is to provide the engine with an air-fuel mixture for burning in the combustion chamber. There are two basic types of fuel systems: the carburetion system, which uses a carburetor to mix air and fuel; and the electronic fuel injection system, which uses a fuel injector to inject fuel into the air going into the combustion chamber. Both systems have some basic parts in common. This unit discusses the basic parts of all fuel systems and the carburetion system in detail. Unit 17 discusses the electronic fuel injection system.

DEVELOPING JOB COMPETENCIES

When you finish reading and studying this unit, you should be able to:

- List and describe the purpose of the basic parts common to all fuel systems.
- Explain the parts and operation of a mechanical and electric fuel pump.
- Describe the operation of a basic carburetor.
- Explain the purpose of each of the carburetor systems.
- Trace the flow of air and fuel through each of the carburetor systems.

BASIC FUEL SYSTEM COMPONENTS

A fuel system has three main jobs: First, it provides for fuel storage. Second, it delivers the fuel to the engine. Third, it mixes the fuel with air in the correct amounts to burn efficiently in the combustion chamber. To perform these jobs, all fuel systems have certain basic parts (Figure 16-1):

1. **Fuel tank:** Stores enough fuel for several hundred miles of operation.
2. **Fuel lines:** Route the fuel through the fuel system.
3. **Fuel pump:** Moves the fuel from the fuel tank into the engine compartment for use in the carburetor or fuel injection system.
4. **Fuel filter:** Removes foreign materials from the fuel on its way to the carburetor or fuel injection system.
5. **Carburetor or fuel injector:** Delivers a metered supply of fuel mixed with the correct amounts of air for efficient combustion in the cylinders. (Electronic fuel injection is discussed in Unit 17).

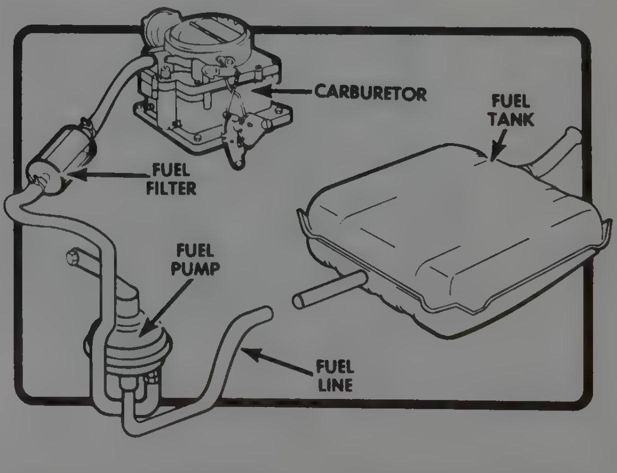


Figure 16-1. Basic parts of a fuel system that uses a carburetor. (Courtesy of Sun Electric Corporation)

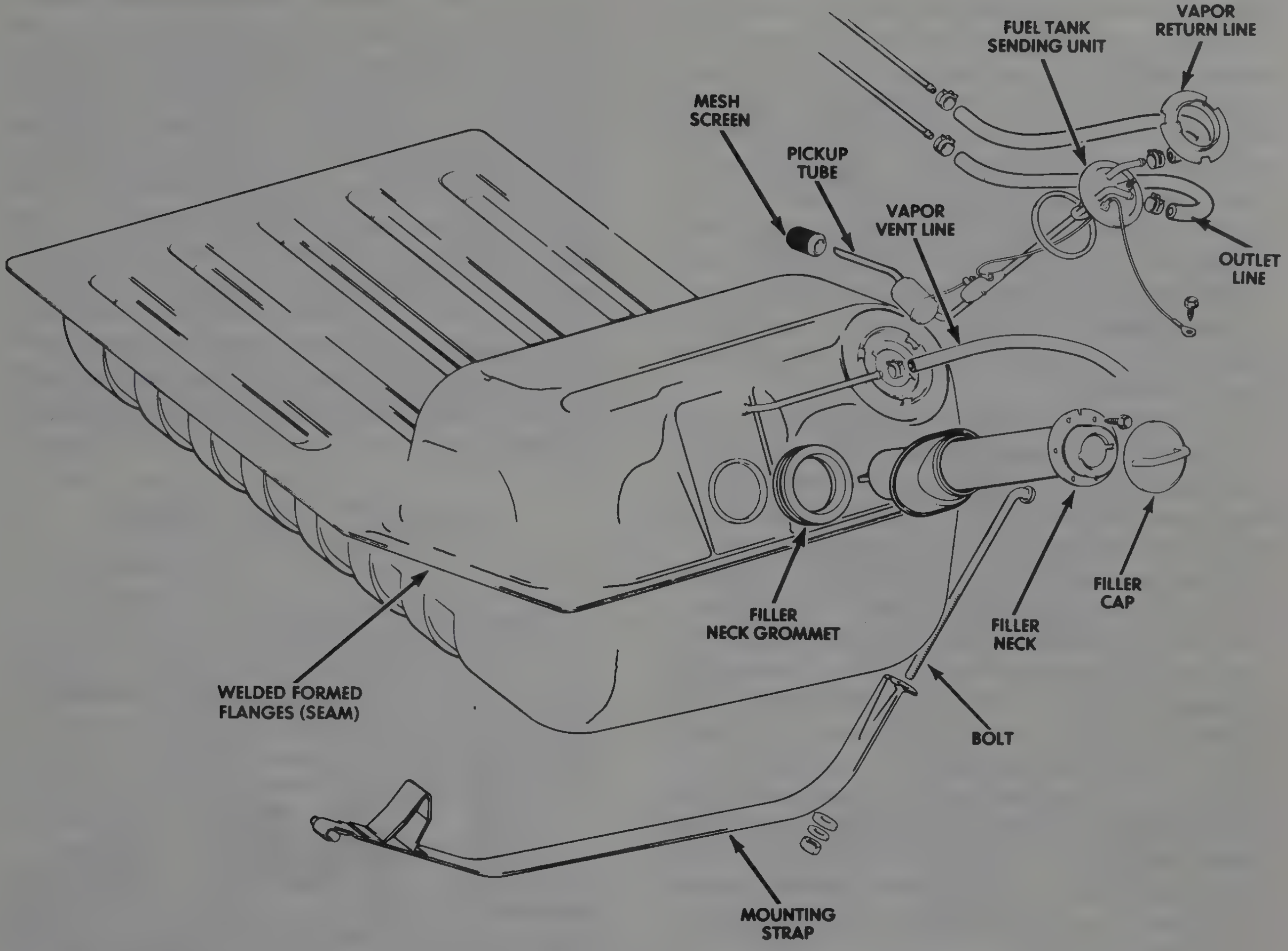

VAPOR RETURN LINE
FUEL TANK SENDING UNIT
MESH SCREEN
PICKUP TUBE
VAPOR VENT LINE
OUTLET LINE
FILLER CAP
FILLER NECK
FILLER NECK GROMMET
WELDED FORMED FLANGES (SEAM)
BOLT
MOUNTING STRAP

Figure 16-2. Components of a typical fuel tank. (Courtesy of American Motors Corporation)

Fuel Tank

The components of a typical **fuel tank** are shown in Figures 16-2 and 16-3. Most passenger car fuel tanks are made of stamped sheet metal sections. The sections are welded at formed flanges by a method called *seam welding*. *Baffles* are used in some fuel tanks to prevent the fuel from sloshing around and causing noise and shifting of weight. By keeping agitation to a minimum, the baffles also improve separation of condensed moisture. *Mounting straps* are used to attach the tank to the vehicle frame or unitized body (unibody). The tank is usually located in an area protected from collision damage such as in front of the rear wheels.

Several lines are attached to the fuel tank. The *outlet line* routes fuel from the tank up to the engine compartment. The outline line is attached to a *pickup* tube located near the bottom of the tank. The fuel pickup tube has a

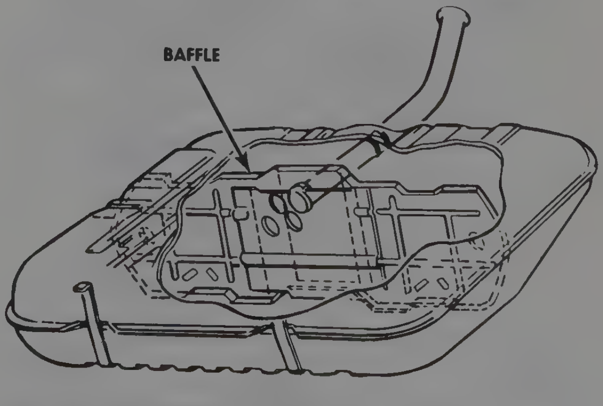


Figure 16-3. Baffles are used in some fuel tanks to prevent fuel from sloshing. (Courtesy of Cadillac Motor Car Division, General Motors Corporation)

mesh screen to block any large particles in the tank from entering the fuel lines. In some vehicles, the pickup is a float, and fuel is always taken from just below the fuel level rather than the bottom. This reduces the possibility of taking in water, unless the fuel level is very low. A *vapor vent line* and *vapor return line* are used to collect and return fuel vapors to the fuel tank.

The *fuel tank sending unit* is an electrical rheostat connected to a float. This unit provides a variable resistance for the fuel gage, allowing the driver to determine the amount of fuel in the tank.

The fuel tank is filled through the *filler neck*. The neck is attached to the tank by a flexible *filler neck grommet*. This protects the filler neck from being ripped out of the tank if the vehicle is in a collision on the side of the filler neck.

Filler necks on late-model vehicles incorporate a *restrictor assembly* (Figure 16-4) to prevent entry of nozzles used on leaded-fuel gasoline station pumps. The restrictor assembly reduces the size (diameter) of the filler neck to a small opening, which is covered by a *trap door*. Unlike the leaded-fuel nozzle, a small-diameter, unleaded-fuel nozzle can pass through the restrictor assembly opening, push open the trap door, and allow the fuel tank to be filled. Catalytic converter contamination caused by leaded fuel is prevented by the restrictor assembly.

All fuel tanks must be vented to allow for expansion and contraction of the fuel as the temperature changes and to allow air in to replace the fuel as it is used. This is accomplished by a *vent tube* or *vented filler cap*. Most vented filler caps (Figure 16-5) incorporate two air valves: a *pressure valve*, which seats on a baffle cup; and a *vacuum valve*, which seats on the pressure valve. The pressure valve is spring-loaded against its seat, and the vacuum valve floats in the *baffle cup*. A slight pressure in the tank or sloshing fuel will force the vacuum valve against the pressure valve and seal off the *vent*. But if the pressure rises above about 1 PSI, the pressure valve will be forced open to relieve the pressure. A vacuum condition in the tank pulls the vacuum valve away from the pressure valve and vents the tank through the center of the pressure valve.

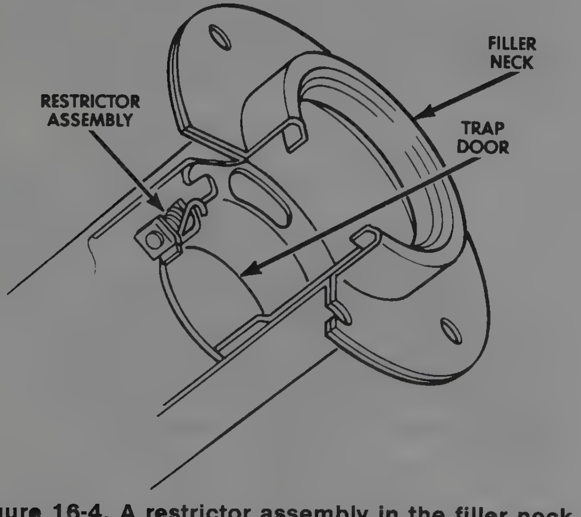


Figure 16-4. A restrictor assembly in the filler neck prevents leaded-fuel nozzles from being inserted. (Courtesy of American Motors Corporation)

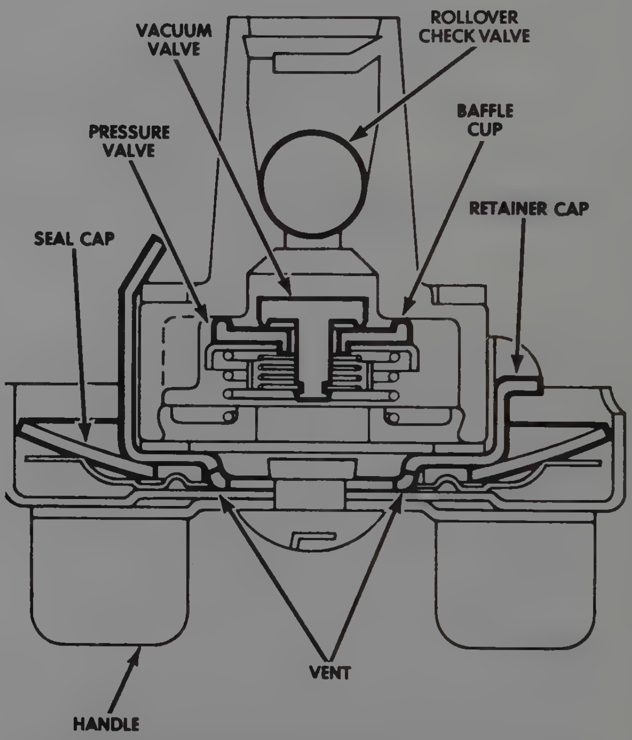


Figure 16-5. Parts of a typical vented filler cap. (Courtesy of American Motors Corporation)

The vented filler cap also includes a *rollover check valve*, which prevents the leakage of fuel from the tank in a "rollover accident." The rollover check valve is a stainless steel ball in a plastic housing, mounted on the fuel tank side of the vented filler cap. If the car is tipped sufficiently, the steel ball drops in its orifice, closing the vent and preventing fuel leakage.

Fuel Lines

Sometimes called *fuel tubes*, the **fuel lines** are constructed primarily of steel tubing except where movement of the line is necessary. When movement is required, flexible hosing, or tubing, is used. Flexible hosing is usually made of synthetic rubber. If the fuel line may be exposed to a gravel road or solid object interference, high-strength flexible hosing is used. This type of hosing is composed of fabric, rubber, and steel wire.

WARNING: Copper tubing should never be used as a fuel line because of its lesser strength. It will break sooner than steel tubing when subjected to vibration and movement.

Fuel Pump

The basic job of the **fuel pump** is to make a constant supply of fuel available at the carburetor. There are two basic types of pumps: mechanical and electrical. The *mechanical fuel pump* is operated by an eccentric cam driven by the engine. The *electrical (or electric) fuel pump* is powered by the vehicle's electrical system.

The mechanical fuel pump (Figure 16-6) is usually mounted on the side of the engine (Figure 16-7). A fuel line is connected from the fuel tank to the fuel pump, and from the fuel pump to the carburetor. Additional lines may be connected to the vapor recovery system.

The mechanical fuel pump shown in Figure 16-8 consists of an *actuating lever*, a *flexible diaphragm* and *diaphragm spring*, an *inlet valve*, and an *outlet valve*. An *eccentric* on the engine

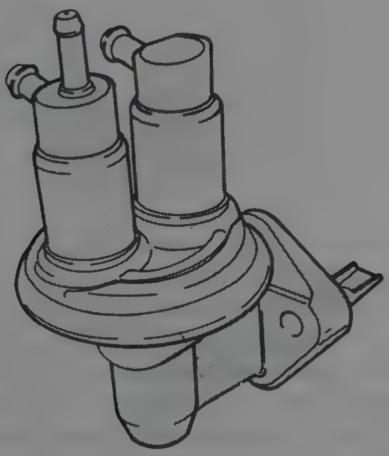


Figure 16-6. Mechanical fuel pump. (Courtesy of Chrysler Corporation)

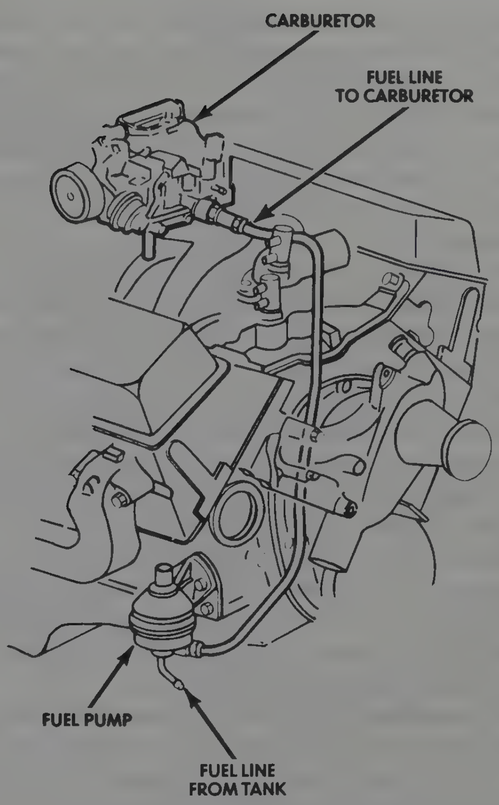

CARBURETOR
FUEL LINE TO CARBURETOR
FUEL PUMP
FUEL LINE FROM TANK

Figure 16-7. Mechanical fuel pump mounted on the side of the engine. (Courtesy of Chevrolet Motor Division, General Motors Corporation)

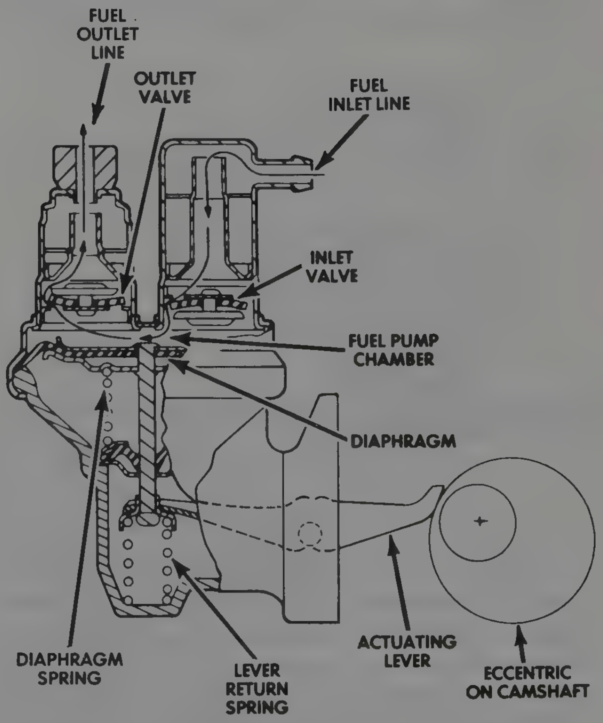

FUEL OUTLET LINE
OUTLET VALVE
FUEL INLET LINE
INLET VALVE
FUEL PUMP CHAMBER
DIAPHRAGM
DIAPHRAGM SPRING
LEVER RETURN SPRING
ACTUATING LEVER
ECCENTRIC ON CAMSHAFT

Figure 16-8. Cross section of a mechanical fuel pump. (Courtesy of American Motors Corporation)

camshaft operates the *actuating lever* that is linked to the diaphragm. The actuating lever pulls the diaphragm to its extended position, pulling fuel through the inlet valve and into the *fuel pump chamber. Lever return spring* pressure pushes the diaphragm toward its relaxed position, forcing fuel out through the outlet valve and into the fuel outlet line.

When the carburetor's *float needle valve* (described later in this unit) closes, fuel pump output is limited to the amount that bleeds back to the fuel tank through the fuel return line. The fuel accumulated in the fuel pump chamber prevents the diaphragm from relaxing. The actuating lever continues to rock up and down, but it is prevented from operating the diaphragm, which is held in its extended position by fuel pressure. Fuel flow from the pump remains stopped until excess pressure bleeds through the fuel return line or the carburetor's *inlet needle valve* opens. This process continuously repeats during engine operation.

An electric fuel pump (Figure 16-9) may be mounted in any convenient location either in or out of the engine compartment. Usually it is mounted close to or inside the fuel tank. When the electric pump is mounted on the fuel tank, the armature has fuel flowing around it, and the pump is called a *wet pump*. There is no danger of explosion, however, because there is never a combustible mixture inside the pump housing.

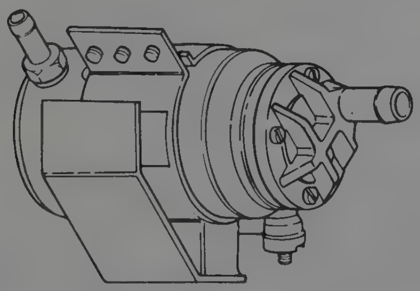


Figure 16-9. Electric fuel pump. (Courtesy of Robert Bosch Sales Corporation)

The electric fuel pump has two main parts: an *electric motor* and a *vane pump*. The electric motor is coupled to the vane pump (Figure 16-10), which is the pumping part. It has a set of *rollers* positioned in *slots* in a *hub*. The hub is driven by the electric motor. As the hub spins, centrifugal force causes the rollers to press against the outer wall of the *housing*. The hub and housing are not concentric. As the hub turns, the rollers must move in and out (back and forth). As the clearance between the rollers and the wall housing increases, a vacuum is formed. Fuel is pulled into the housing through an *inlet*. Further rotation causes the clearance to get smaller. Fuel is then discharged from the *outlet*.

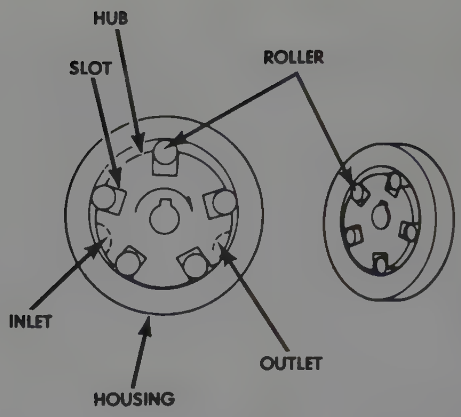


Figure 16-10. The pumping part of an electric fuel pump is called the vane pump. (Courtesy of Nissan Motor Corporation in U.S.A.)

The electric motor of the pump is a permanent magnet type of motor. A *key switch*, or *ignition switch*, is used to activate the electric motor. An *oil pressure* switch is used in many applications so that if the engine stops, the fuel pump will also stop, even if the ignition switch is on. This is a safety feature in the event of a collision.

The electric fuel pump delivers several times the quantity of fuel actually required. Excess fuel is diverted at the pressure regulator and flows under low pressure back to the fuel tank. The *check valve* prevents abrupt drop of pressure in the fuel pipe or line when the engine is stopped. Fuel flow through the electric fuel pump is shown in Figure 16-11.

Fuel Filters

By keeping the gasoline clean on its way to the carburetor, **fuel filters** prevent clogging of the fuel passages in the carburetor. Also, fuel filters reduce the amount of water that enters the carburetor, which reduces the likelihood of freeze-up in the carburetor and engine misfire.

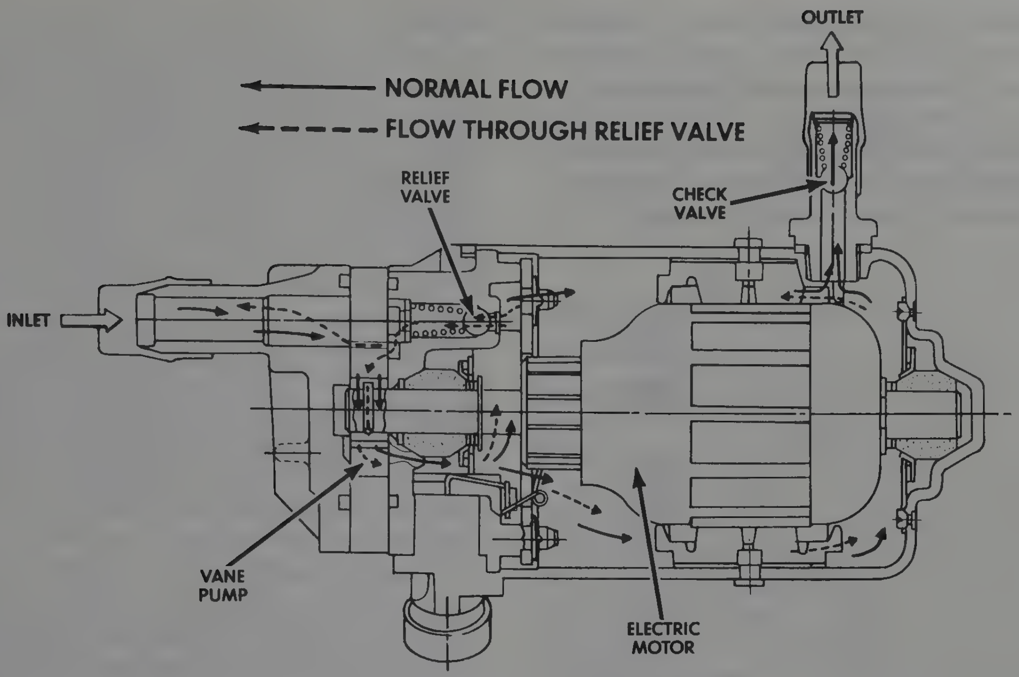

OUTLET
NORMAL FLOW
FLOW THROUGH RELIEF VALVE
RELIEF VALVE
CHECK VALVE
INLET
VANE PUMP
ELECTRIC MOTOR

Figure 16-11. Cross section showing how fuel flows through an electric pump. (Courtesy of Robert Bosch Sales Corporation)

Most fuel systems have at least one fuel filter to remove impurities from the gasoline.

Filters or screens incorporated in the fuel tank were mentioned earlier in this unit under the heading of "Fuel Tank." These filters are used on most vehicles. They are usually made of a porous bronze material that separates dirt and water from the gasoline before it flows to the fuel pump inlet line. As the fuel sloshes in the tank, it washes these impurities back into the tank, where they settle to the bottom.

In-line fuel filters are located between the fuel pump and carburetor and are disposable (Figure 16-12). In this type of filter, gasoline enters the *fuel inlet* and flows around the outside of a *paper element*, through the paper element to its center, and then to the *fuel outlet*. Since this type of fuel filter is relatively inexpensive, the paper element is not replaceable.

Another type of in-line fuel filter is usually mounted at the fuel inlet of the carburetor

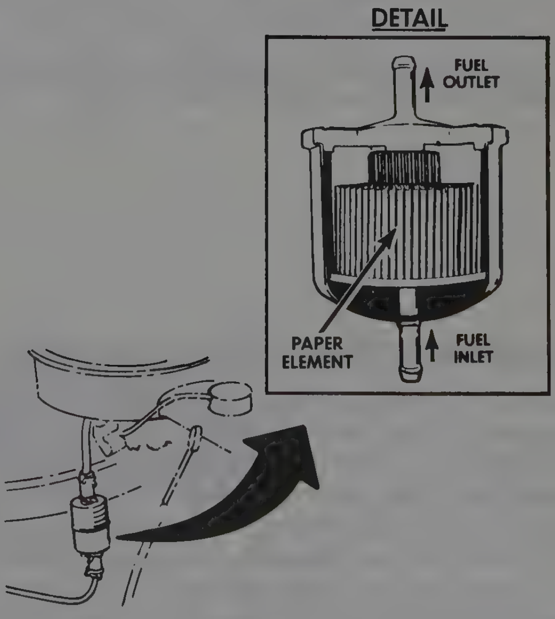

DETAIL
FUEL OUTLET
PAPER ELEMENT
FUEL INLET

Figure 16-12. An in-line, disposable type of fuel filter is located between the fuel pump and the carburetor. (Courtesy of Nissan Motor Corporation in U.S.A.)

(Figure 16-13). The *filter element* may be paper or screen. It is held in position in the carburetor by a *spring* at one end and the *fuel inlet nut* at the other end. A *gasket* at the fuel inlet nut prevents fuel leakage. Fuel enters the inlet nut and flows through the filter element, where it is cleaned before it enters the carburetor.

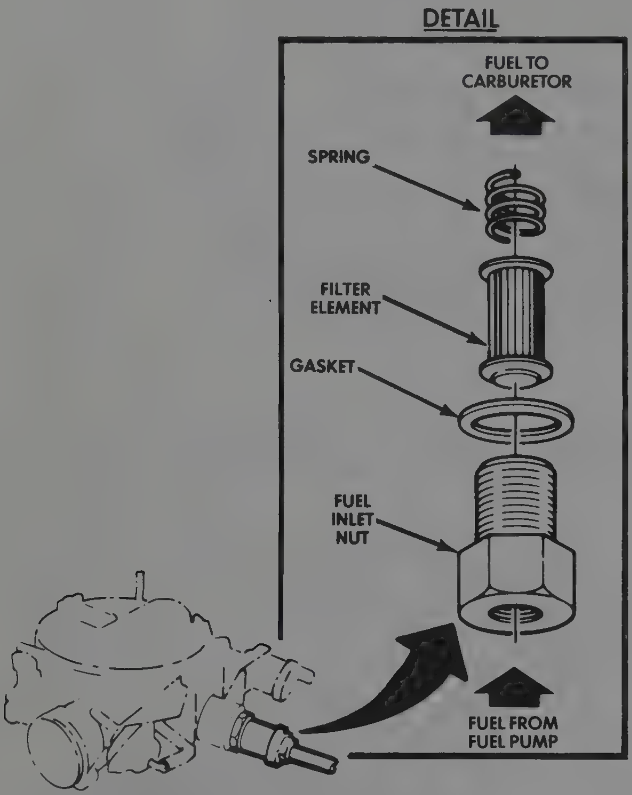


Figure 16-13. An in-line, carburetor-mounted fuel filter. (Courtesy of American Motors Corporation)

CARBURETOR FUNDAMENTALS

Raw fuel will not provide efficient combustion unless it is mixed with a sufficient amount of air. A **carburetor** delivers a metered supply of fuel mixed with the correct amounts of air (an air-fuel mixture) for efficient combustion in the cylinders. (A **fuel injector**, discussed in Unit 17, performs the same function.) An understanding of how the process works requires an understanding of the physical principles upon which the carburetor operates.

Flow

Physics (the science that deals with matter and energy and their interaction) has established that matter can exist in three different states: *solid, liquid,* and *gas*. Two of these states, liquid and gas, are known as *fluids*, meaning that they will flow readily from one container to another. For example, water and air are both fluids, and both will flow through a tube or hose.

Movement of any fluid is the direct result of a difference in pressures. The direction of flow is always toward the point of least pressure. Water flows through a garden hose because the nozzle end is open to the atmospheric pressure, whereas the other end is subject to the pressure in the water supply line. The Compressed air flows through a shop hose because the pressure in the air storage tank is greater than the atmospheric pressure at the nozzle.

An internal combustion engine can be likened to a very efficient vacuum pump. Every time a piston goes down on an intake stroke, it creates a vacant space. Atmospheric pressure tries to fill this space by flowing through the carburetor. The rate of air flow through the carburetor is controlled by the throttle setting.

Low Pressure

Pressure that is lower than atmospheric pressure is a **vacuum**. Vacuum is measured in inches of mercury (in.Hg.). The following illustration explains why it is measured this way.

Suppose that an open container of mercury has a tube standing in it and a vacuum gage connected to measure the vacuum (Figure 16-14). As long as the top end of the tube is open to atmospheric pressure, the level of the

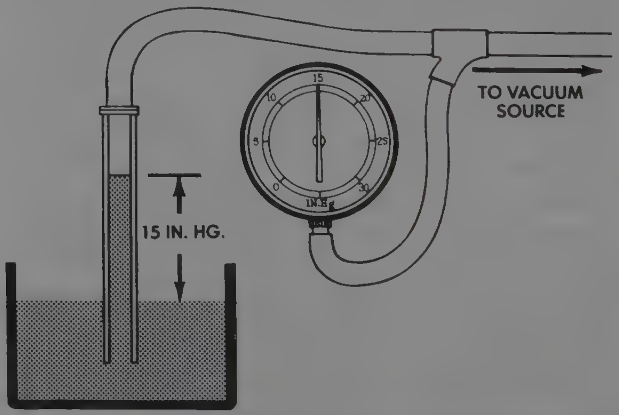


Figure 16-14. Vacuum is measured in inches of mercury. (Courtesy of Chrysler Corporation)

mercury inside the tube will be the same as the level in the open container. However, if the top end of the tube is connected to a vacuum source (an area lower than atmospheric pressure), the level of the mercury inside the tube will rise. If a perfect vacuum existed above the mercury in the tube, the level would rise 29.92 inches in the tube, and the gage would read 29.92 in.Hg. Less vacuum would pull the mercury up less far in the tube.

In automotive terminology, any low pressure below the *throttle valve* (discussed later in this unit under the heading of "Basic Carburetor Construction") is called **manifold vacuum**. Any low pressure above the throttle valve is called simply **low pressure**.

Venturi Principle

Discovered about 200 years ago, the *venturi principle* (Figure 16-15) states: Fluid flowing through a restriction increases in velocity and decreases in pressure. In other words, when a fluid reaches a restriction, it must speed up to maintain the same volume of flow. However, speeding up increases the fluid's kinetic energy, or energy of motion. Since energy cannot be created from nothing, the fluid must lose another form of energy, potential energy, to gain kinetic energy. The gain in kinetic energy is offset by a decrease in pressure. Total energy remains the same.

The venturi principle is used in a carburetor to create a flow of fuel.

Atomization and Vaporization

In order to burn efficiently, a fuel must be changed from a liquid to a gas. Changing a liquid to a gas is called *evaporation* or **vaporization**.

Atomization means breaking the liquid fuel into very small particles so that it can readily vaporize and mix with air. With the fuel broken into small particles, there is more air contact and thus more efficient vaporization.

Air-Fuel Ratio

About 15 pounds of air are required to completely burn 1 pound of gasoline. An air-fuel ratio of 15 to 1 is based on this calculation. Weight rather than volume is considered, because the volume of air and fuel can change with temperature and pressure changes.

An air-fuel mixture of less than 15 pounds of air per pound of fuel is a *rich* mixture, since the proportion of fuel to air is greater. A mixture of more than 15 pounds of air per pound of fuel is a *lean* mixture, since the proportion of fuel to air is smaller. Most engines can operate on mixtures within a range of 8 to 1 (very rich) to 17 to 1 (slightly lean). However, mixtures richer than 11 to 1 are seldom used, regardless of conditions.

Because an automotive engine is subject to so many different demands, the carburetor must be able to vary the ratio of fuel to air and the amounts of this ratio fed to the cylinders. For example, an engine needs a rich mixture for idling, heavy loads, and high speeds. It needs a leaner mixture for normal cruising and light loads. These variations in mixture and amount (quantity) are automatically regulated by the carburetor.

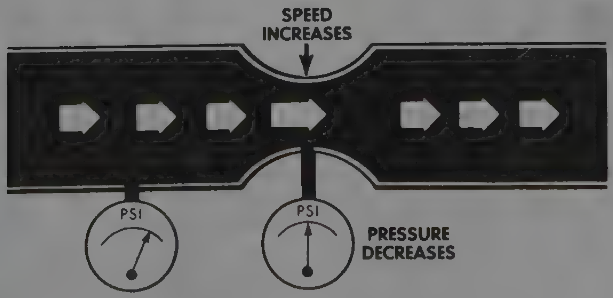


Figure 16-15. This drawing illustrates the venturi principle. (Courtesy of Chrysler Corporation)

BASIC CARBURETOR CONSTRUCTION

Basic carburetor components are shown in Figure 16-16. A tube, or *barrel*, permits an airstream (airflow) to enter at the air horn and pass through to the intake manifold and cylinders. The fuel is vaporized and mixed into the airflow in the barrel.

Manifold vacuum is what causes the airflow. As far as the carburetor is concerned, the engine is nothing but an air suction pump. The pistons alternately move down on their intake strokes, creating a vacuum in the combustion chamber. Because the intake valves are open at this time, a vacuum is also present in the intake manifold. However, the air above the carburetor tube (barrel) is at atmospheric pressure. The difference in pressure forces the air down the barrel to fill the vacuum. With the engine operating, there is a continuous stream of air through the barrel with more air flowing at high speed and less air at low speed.

A supply of fuel is stored in the carburetor *float bowl*. The *main nozzle* directs fuel from the float bowl to the barrel, where the fuel is sprayed in the airflow.

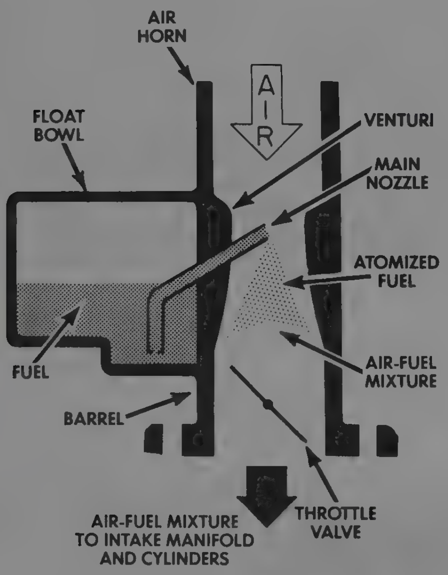


Figure 16-16. Basic parts of a carburetor. (Courtesy of Chevrolet Motor Division, General Motors Corporation)

The **venturi**, which is a constriction in the carburetor barrel, pulls the fuel into the air flow from the float bowl. With the venturi at the main nozzle discharge opening, the main nozzle works as an atomizer. As the stream of air flows past the main nozzle, the venturi air pressure falls. The reduced pressure in the venturi permits atmospheric pressure in the carburetor float bowl to force the fuel through the nozzle and into the airstream. The fuel atomizes in the airflow, and vaporization is aided by the reduced pressure.

The size of the venturi is a compromise between low-speed and high-speed operation requirements. At low speeds, when airflow is minimum, a small venturi is desirable. At high speeds, a large venturi is desirable, so that airflow is not restricted. Often two or more venturis work in series.

The **throttle valve** is a butterfly-type valve placed in the barrel near the bottom to control the volume of air flowing through the barrel. The throttle valve is opened and closed by mechanical linkage to the accelerator pedal. Opening the throttle valve lets the airflow through unrestricted. Closing it restricts the airflow, so less air is taken in.

The throttle valve position also has an important effect on manifold vacuum. With the throttle valve closed and less air entering to fill the void, manifold vacuum stays high. When the throttle valve is opened, the airflow rushes in to fill the void, and vacuum drops.

If an engine operated at the same speed and with the same load all the time, a good volatile fuel introduced into the airflow at a constant rate would be sufficient. The fuel would vaporize and mix with the air, and no other controls would be necessary. However, the amount of air-fuel mixture must be varied to change speed and/or power output, and the air-fuel ratio must be varied to suit operating conditions. Therefore, to accomplish this, other systems are needed in the carburetor.

CARBURETOR SYSTEMS

As shown in the discussion under the heading, "Basic Carburetor Construction," the quantity of the air-fuel mixture that goes to the cylinders is determined by the position of the throttle valve. This in turn determines engine speed. When this air-fuel mixture is not rich enough to develop the needed power, or when the carburetor is inoperative because of low airflow, certain other systems are needed to provide the necessary enrichment. Consequently, a carburetor has six basic systems:

- Float system
- Idle system
- Main metering system
- Power system
- Acceleration system
- Choke system

Each of these systems has a specific function, and in some cases the functions overlap.

Float System

The purpose of the **float system** (Figure 16-17) is to assure that there will be an ample supply of fuel for the other basic systems of the carburetor to meet any operating conditions. The fuel is supplied to the float system by the fuel pump, which forces the fuel to the carburetor at a constant, specific pressure, regardless of engine speed. The float system consists of the *float bowl, float, needle valve,* and *needle seat*.

Fuel in the float bowl must be maintained at a specified level for correct fuel metering under all driving conditions. The float system accomplishes this by using a float, which exerts force against a needle valve to shut off fuel flow into the bowl when the specified level is reached. Fuel from the fuel pump enters through the *fuel inlet* and into the float bowl through an orifice called the needle seat. As the level in the float bowl rises, the float seats the needle valve against the needle seat. When fuel from the bowl is being used, the float drops to allow the needle valve to open, and fuel enters past the needle valve to maintain the fuel level (Figure 16-18).

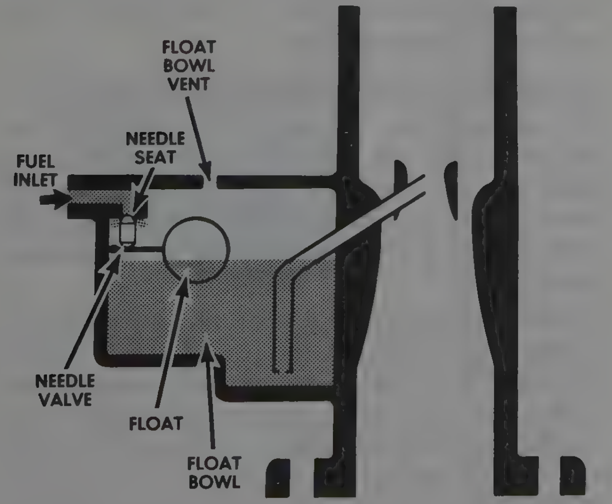


Figure 16-17. The fuel necessary for any carburetor system is supplied by the float system. (Courtesy of Chevrolet Motor Division, General Motors Corporation)

The fuel level is controlled by the float setting and is an important part of carburetor calibration. If the fuel level is lower than specified, less fuel can be pulled into the venturi. The result is a lean air-fuel mixture.

A low fuel level results in poor performance in the main metering system (discussed later in this unit) and a definite loss of power. A high fuel level can cause the main metering system to deliver fuel prematurely, resulting in fuel spillage during normal car maneuvering. Either of these conditions causes excessive fuel consumption and an over-rich condition.

The float system is perhaps one of the most important systems in the carburetor, because the correct operation of the other systems depends on the right level of fuel being maintained in the float bowl.

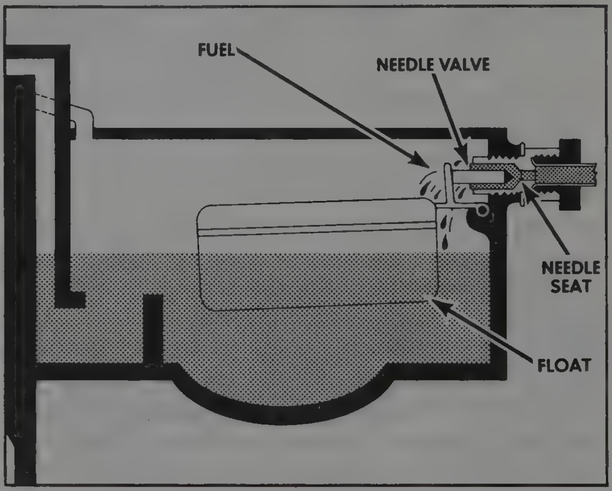


Figure 16-18. When the fuel level drops, the float drops, allowing the needle valve to open and allow fuel in. (Courtesy of Chrysler Corporation)

Idle System

During engine idle operation, airflow through the carburetor venturi is very low and therefore insufficient to meter fuel properly from the main discharge nozzle. The purpose of the **idle system** is to provide the proper air-fuel mixture during engine idling and low-speed operation. The idle system consists (Figure 16-19) of an *idle tube, idle passage, idle air bleed, off-idle ports, idle mixture screw,* and *idle discharge port*.

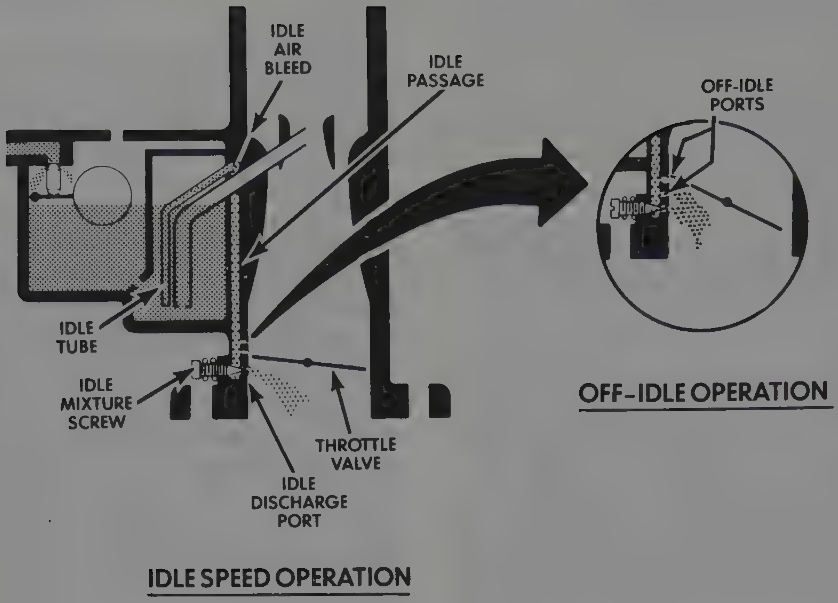


Figure 16-19. The idle system during idle speed operation and during off-idle operation (also referred to as slow speed operation). (Courtesy of Chevrolet Motor Division, General Motors Corporation)

During *idle speed operation*, the throttle valve is slightly open, allowing a small amount of air to pass between the wall of the carburetor barrel and the edge of the throttle valve. Since there is not enough airflow for venturi action, the fuel is made to flow by the application of vacuum directly through the idle system to the fuel in the carburetor float bowl.

The low pressure (manifold vacuum) below the throttle valve causes the fuel to flow through the idle tube into the idle passage. There it is mixed with air from the idle air bleed. (The purpose of any **air bleed** is to provide a passage for air to enter the fuel.) This is the first stage of atomizing the fuel.

The air-fuel mixture continues down the passage, past the off-idle ports. At this point, these off-idle ports act as air bleeds to further break up the air-fuel mixture. The air-fuel mixture flows past the idle mixture screw into the idle discharge port. The idle mixture screw controls the idle mixture and is turned *in* (clockwise) to lean the idle mixture and backed *out* (counterclockwise) to richen it.

As the throttle valve is opened during slow speed or *off-idle operation*, the off-idle ports are exposed to manifold vacuum. At this time they begin feeding extra air-fuel mixture for off-idle requirements. Thus, the off-idle ports have a dual purpose. At idle, they act as air bleeds, but during the off-idle operation, they change to air-fuel mixture feeds.

Idle System Adjustments. There are two adjustments on the idle system: *idle speed* and *idle mixture*. These two adjustments are closely related. It is often necessary to alternate between the two a number of times to obtain the most desirable air-fuel mixture for the idle speed setting.

Idle speed is adjusted by turning an *idle speed screw* on the throttle linkage (Figure 16-20). As the screw is turned in, it opens the throttle valve slightly, providing a larger air passage into the manifold. The additional air mixes with the rich, idle air-fuel mixture coming from the idle discharge port. It may also draw some fuel from the off-idle port, because the off-idle port will be partially exposed to manifold vacuum.

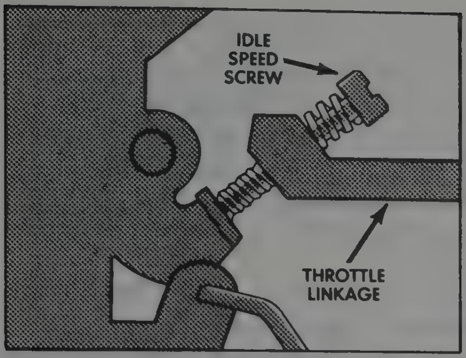


Figure 16-20. The idle speed screw is used to open the throttle valve. (Courtesy of Chrysler Corporation)

Another factor that may draw fuel from the off-idle port is the passage of air around the throttle valve. When the airflow passes through the narrow opening, it speeds up, just as it does in a venturi. As in a venturi, the speedup in the airflow causes a reduction in pressure. The combination of manifold vacuum and the pressure reduction draws fuel from the idle discharge port.

Idle mixture is adjusted by turning the *idle mixture screw* (Figure 16-21). The idle mixture screw is a type of metering needle valve, located in the idle discharge port. The position of the idle mixture screw determines how much of the idle discharge port will be exposed to manifold vacuum. In other words, the position of the idle mixture screw controls the amount of air-fuel mixture that is discharged into the airflow past the slightly opened throttle valve. This is why it is necessary to alternate adjustments of idle speed and idle mixture until the correct combination is found.

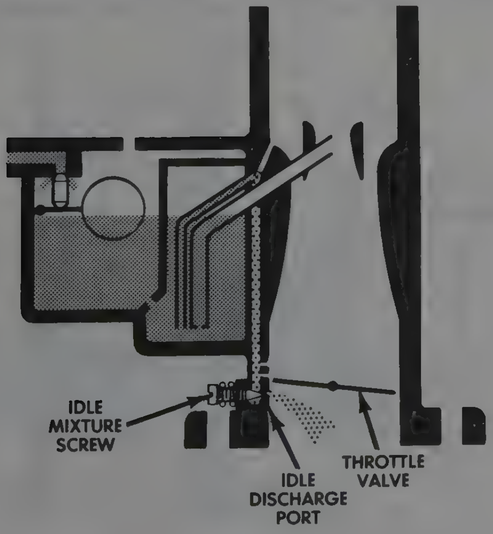


Figure 16-21. The position of the idle mixture screw determines how much of the idle discharge port will be exposed to manifold vacuum. (Courtesy of Chevrolet Motor Division, General Motors Corporation)

Main Metering System

The middle, or cruising, range of the carburetor is controlled by the **main metering system** (Figure 16-22). The main metering jet is a very accurately machined orifice that controls the fuel flow through the main well that houses the main nozzle. An air bleed in the well and the air bleeds in the main nozzle keep the mixture constant throughout the operating range of the main metering system for maximum economy. The main metering system consists of a *main metering jet* and a *main nozzle* with *air bleeds*.

As the throttle valve is opened, air velocity through the venturi increases. This in turn greatly decreases the pressure in the venturi at the main nozzle and causes the fuel to be pushed through the main metering jet and up the main nozzle. As the fuel enters the main nozzle, it is mixed with air through the calibrated holes (air bleeds) in the main nozzle. This air aids in atomizing the air-fuel mixture for improved distribution. The air-fuel mixture continues through the main nozzle and enters the airflow at the venturi. At this point, it is mixed with the incoming air and is carried past the throttle valve and into the manifold for distribution to the engine cylinders.

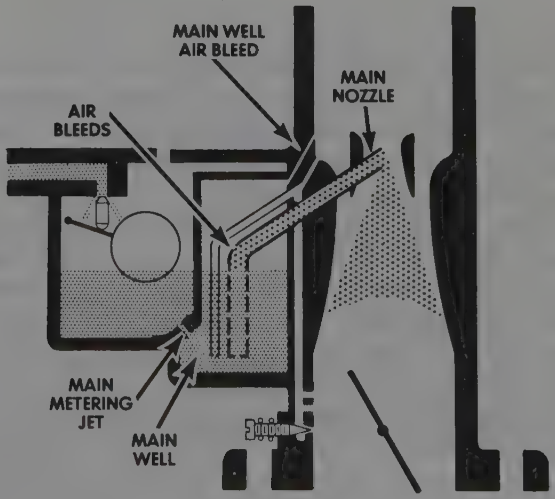


Figure 16-22. The main metering system provides fuel for the middle, or cruising, range. (Courtesy of Chevrolet Motor Division, General Motors Corporation)

Power System

Maximum engine power requires the use of all available air for combustion. To accomplish this, a slightly richer air-fuel mixture is needed. The **power system** (Figure 16-23) supplies the additional fuel by supplementing the main metering system. The power system consists of a *piston spring*, a *power piston*, a *manifold vacuum passage*, a *power valve*, and a *power restriction* located between the power valve and the main well.

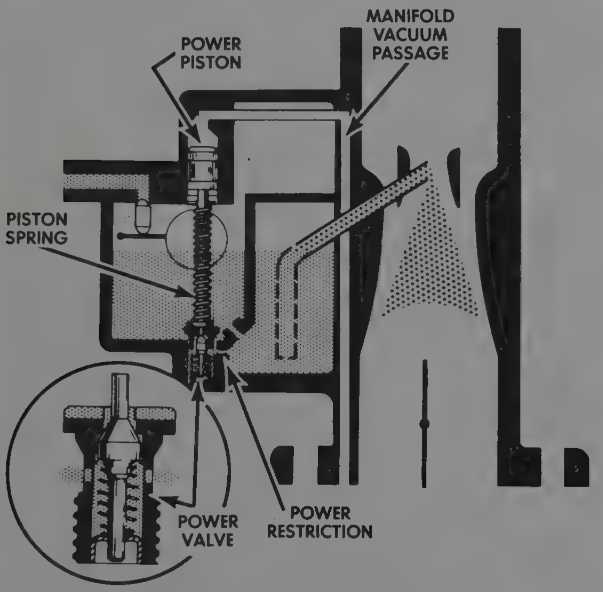


Figure 16-23. The power system is used to supplement the main metering system by providing fuel for high speed operation. (Courtesy of Chevrolet Motor Division, General Motors Corporation)

The power piston determines when the power valve opens, and the power restriction determines how much fuel (in addition to the fuel already supplied by the main metering jet) will be added to the main well.

The power system, controlled by manifold vacuum, provides an additional fuel inlet to the main nozzle under low manifold vacuum conditions. Normally, the power piston is held up by high manifold vacuum. However, any time manifold vacuum falls below the tension of the piston spring, the piston springs' tension forces the power piston down. This opens the power valve to increase the fuel flow to the main nozzle. The power system is operative only when the engine demands fuel enrichment for extra power.

Acceleration System

A richer air-fuel mixture is provided for acceleration by the **acceleration system** (Figure 16-24). The acceleration system consists of a *pump plunger, pump well, intake check ball, discharge passage, duration spring, return spring, mechanical linkage,* and *discharge check ball.*

When the throttle valve is opened rapidly for acceleration, the airflow and manifold vacuum change almost instantly. Because of the great difference in weight between air and fuel, any sudden change caused by the throttle valve opening results in an immediate increase in air intake. However, the fuel, having greater weight, tends to lag behind. The result is momentary leanness of the air-fuel mixture. The acceleration system provides the extra fuel necessary to overcome this leanness and give smooth operation on all throttle valve openings. This is accomplished by discharging extra fuel into the venturi airflow whenever the throttle valve is opened.

The acceleration system utilizes a *pump plunger* that is linked to the throttle lever by *mechanical linkage* (Figure 16-24). Any opening of the throttle valve causes the pump plunger to move downward in the *pump well*. This action forces fuel through the *pump passage* and out the *pump discharge passage* into the incoming airstream.

As the throttle is closed, the pump plunger is lifted up in the pump well, creating a low pressure below the pump plunger. The intake check

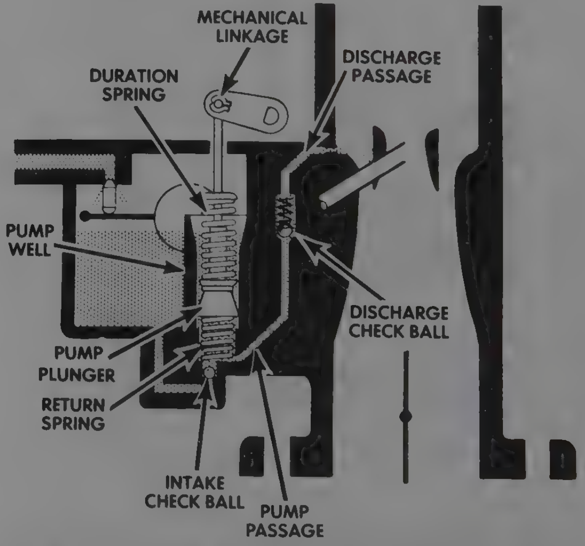


Figure 16-24. The acceleration system provides a richer air-fuel mixture for rapid acceleration. (Courtesy of Chevrolet Motor Division, General Motors Corporation)

ball is lifted off its seat, allowing fuel to flow into the pump well. At the same time, the discharge check ball seats, preventing air from leaking into the discharge passage. The duration spring and return spring work together to give a controlled, smooth discharge for a moment after the accelerator pedal stops moving.

Choke System

The purpose of the **choke system** (Figure 16-25) is to provide a richer air-fuel mixture for cold engine starting and operation. Mixture enrichment is necessary because fuel vapor has a tendency to condense on cold engine parts such as the inside area of the intake manifold and cylinder head. This condensation decreases the amount of combustible mixture available in the engine cylinder. The choke system consists of a *thermostatic coil, choke valve, heat stove, choke piston,* and *fast idle and choke unloader linkage*.

When the engine is cold, a thermostatic coil holds the choke valve closed. This cuts down the air supply and raises the vacuum applied to the fuel outlets, so that more fuel than usual can be drawn into the cold engine. As the engine warms up, the manifold vacuum supplied to the choke thermostatic housing, through the manifold vacuum passage, pulls hot air from the heat stove to heat the thermostatic coil. The thermostatic coil relaxes gradually until the choke valve is fully opened. The choke piston is used as an aid to offset the tension of the thermostatic coil and in choke valve opening.

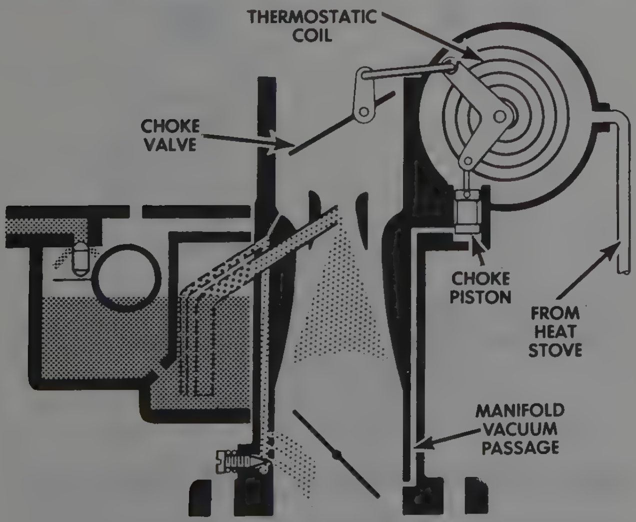


Figure 16-25. The choke system provides a richer air-fuel mixture for cold starting. (Courtesy of Chevrolet Motor Division, General Motors Corporation)

Airflow also tends to open the choke valve slightly, depending on the air demanded by the engine. This airflow action can be seen by watching the choke valve during engine cranking. The choke valve will move slightly every time a cylinder is on the intake stroke.

During warm-up, it is necessary to provide a faster idle to prevent engine stalling. This is accomplished through the *fast idle and choke unloader linkage* (Figure 16-26). A *fast idle cam* is connected by a *rod* to a *lever* on the *choke valve shaft*. The *fast idle adjustment screw* on the *throttle lever* contacts graduated steps on the fast idle cam. When properly set, it allows a faster idle, which prevents engine stalling during the warm-up period. When the engine is completely warm and the choke valve is wide open, the fast idle cam rotates so that the fast idle adjustment screw rests on the low step on the fast idle cam, where normal idle speed is obtained. Some carburetors have separate idle adjustment screws for fast and curb (normal).

If the engine becomes flooded during the starting period, the choke valve can be partially opened manually to allow increased airflow through the carburetor. This is accomplished by depressing the accelerator pedal to the floor. The *unloader tang* on the throttle lever contacts the edge of the fast idle cam and thus partially opens the choke valve. The extra air produces a leaner air-fuel mixture so that the engine will start.

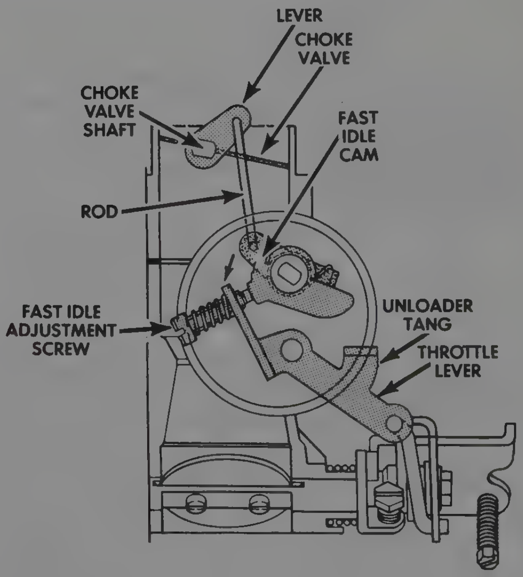


Figure 16-26. Fast idle and choke unloader linkage. (Courtesy of Chevrolet Motor Division, General Motors Corporation)

INTAKE MANIFOLD

The carburetor is mounted on the engine to an **intake manifold** (Figure 16-27). An intake manifold is a system of pipes. It directs the air-fuel mixture into each intake port in the cylinder head. A mixture of equal air-fuel ratios must reach each cylinder; otherwise, one cylinder will be lean, another rich.

To ensure that equal air-fuel ratios reach each cylinder, accurate control of manifold temperature is necessary. The fuel must be kept in a vapor state as it passes through the manifold. If the manifold is cold, gasoline particles will "condense out" (turn to liquid) and collect on the bottom of the manifold. This will "lean out" the air-fuel mixture reaching the cylinder. Eventually, enough of this liquid fuel will collect and enter one or more of the cylinders, causing those cylinders to run rich while the others run lean.

It is easier to distribute equal quantities of the air-fuel mixture to the branches of a manifold than it is to distribute a combination of gas and liquid. This is particularly true when the velocity through the manifold is slow, such as at partial throttle.

To improve manifold distribution through proper vaporization, exhaust gases may be passed through a passage called a heat riser passage (Figure 16-28), which surrounds a portion of the intake manifold. When the engine is warm, little or no exhaust gases are allowed to pass through the passage, since sufficient heat is radiated to the intake manifold from the hot parts of the engine. However, when the engine is cold, some of the exhaust gases are directed through the heat riser passage to ensure quick, smooth warm-up. A thermostatically controlled *heat riser valve* is used to automatically direct the exhaust gases, either through the heat riser passage when the engine is cold or directly to the exhaust pipe when the engine is warm. The *thermostatic spring* and the *counterweight* close the heat riser valve when the engine is cold. As the thermostatic spring becomes hot, it unwinds, allowing the counterweight to open the heat riser valve.

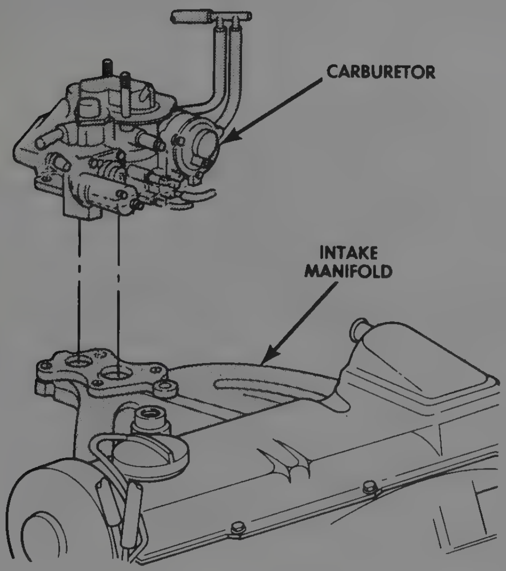


Figure 16-27. The carburetor is mounted on an intake manifold. (Courtesy of Chrysler Corporation)

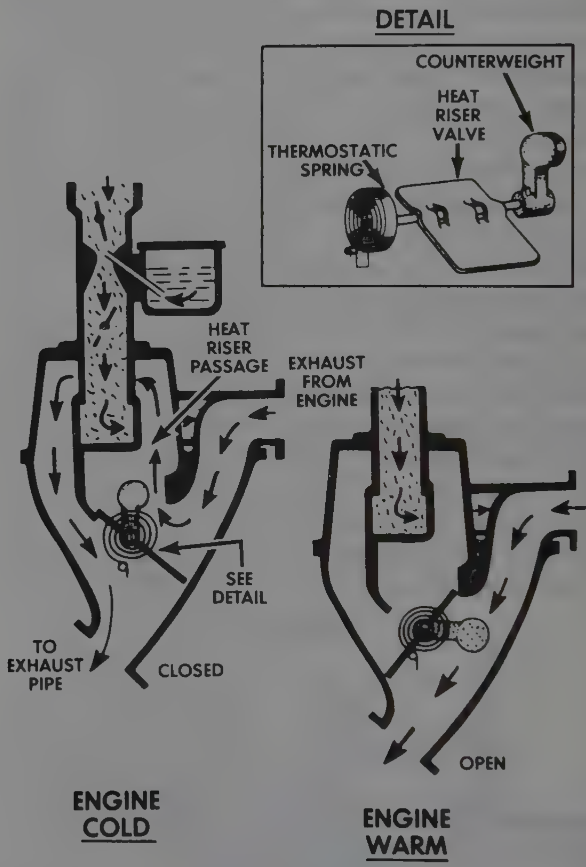
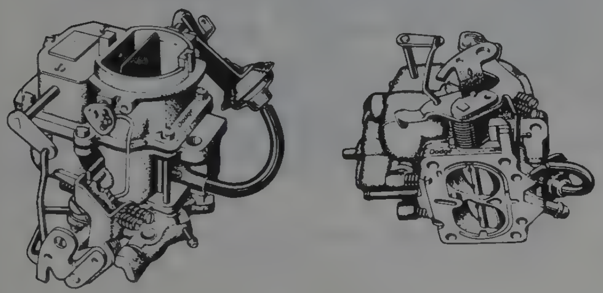


Figure 16-28. The heat riser valve routes hot exhaust gases around the intake manifold to heat the air-fuel mixture. (Courtesy of Sun Electric Corporation)

MULTIPLE-BARREL CARBURETORS

Discussion thus far has concerned a carburetor with a single barrel and one throttle valve. However, carburetors are manufactured with one, two, three, and four barrels. Although some small engines use a carburetor with a single barrel, others with higher engine displacements require a larger carburetor. A very large single-barrel carburetor with a very large venturi might meet the air-fuel needs of such vehicles at high speed, but not at low speed. Consequently, a multiple-barrel carburetor is needed. A **multiple-barrel carburetor** has several small venturis and barrels. The small venturis allow good low-speed operation and also provide enough air-fuel delivery for high-speed operation.

The two-barrel carburetor shown in Figure 16-29 has a single float and choke system for both barrels. Each barrel is equipped with its own idle, main metering, power, and acceleration systems. In three-barrel and four-barrel carburetors (Figure 16-30), the barrels usually share float and choke systems.



TOP VIEW

BOTTOM VIEW

Figure 16-29. Two-barrel carburetor. (Courtesy of Chrysler Corporation)

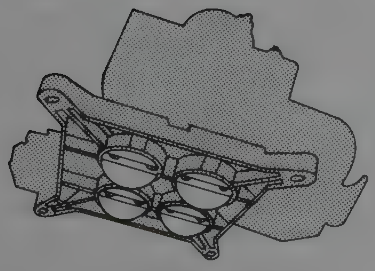


Figure 16-30. Four-barrel carburetor. (Courtesy of American Motors Corporation)

VARIABLE VENTURI CARBURETORS

Discussion thus far has concerned carburetors with venturis of one fixed size. This type of carburetor is called a *fixed venturi carburetor*. An idle system and power system are necessary to handle variations in airflow through this type of carburetor. At low engine RPM, for example, airflow is not great enough to make the fixed venturi carburetor operate. Therefore, an independent idle system is employed. During low manifold vacuum accelerations (such as climbing a hill), a power system is needed.

The **variable venturi carburetor** is able to change the size of the venturi to maintain sufficient air velocity and pressure drop for the main metering system. A cross section of a variable venturi carburetor is shown in Figure 16-31. A movable, rounded valve called a *venturi valve* is positioned in the carburetor airstream (airflow). It functions as the venturi. Linkage from the venturi valve is connected to a *control vacuum diaphragm*.

The venturi valve position is controlled by two forces, that of spring pressure and that of control vacuum. The pressure from the *spring* acts to close the venturi valve. The control vacuum acts through a *rubber diaphragm* to open the venturi valve. The control vacuum is located below the venturi valve and above the throttle valve. It is channeled through the *carburetor body* and *diaphragm housing* to the rear of the control vacuum diaphragm.

An increase in throttle valve opening results in a stronger control vacuum signal. This causes the venturi valve to open and increase the venturi size as more air flows. Since the venturi valve is not linked directly to the throttle valve shaft, the control vacuum and spring can select the precise air-fuel ratio for all speed and load conditions.

Tapered *metering rods* are attached to the venturi valve. There is one rod and *jet* for each barrel of the carburetor. The metering rod moves back and forth in the jet when the venturi valve moves. When the venturi valve is closed, the largest diameter portion of the metering rod is in the jet. When the venturi valve is in the wide-open position, the smallest diameter of the metering rod is in the jet. Therefore, the effective metering area of the fuel is controlled by the metering rod position in the jet.

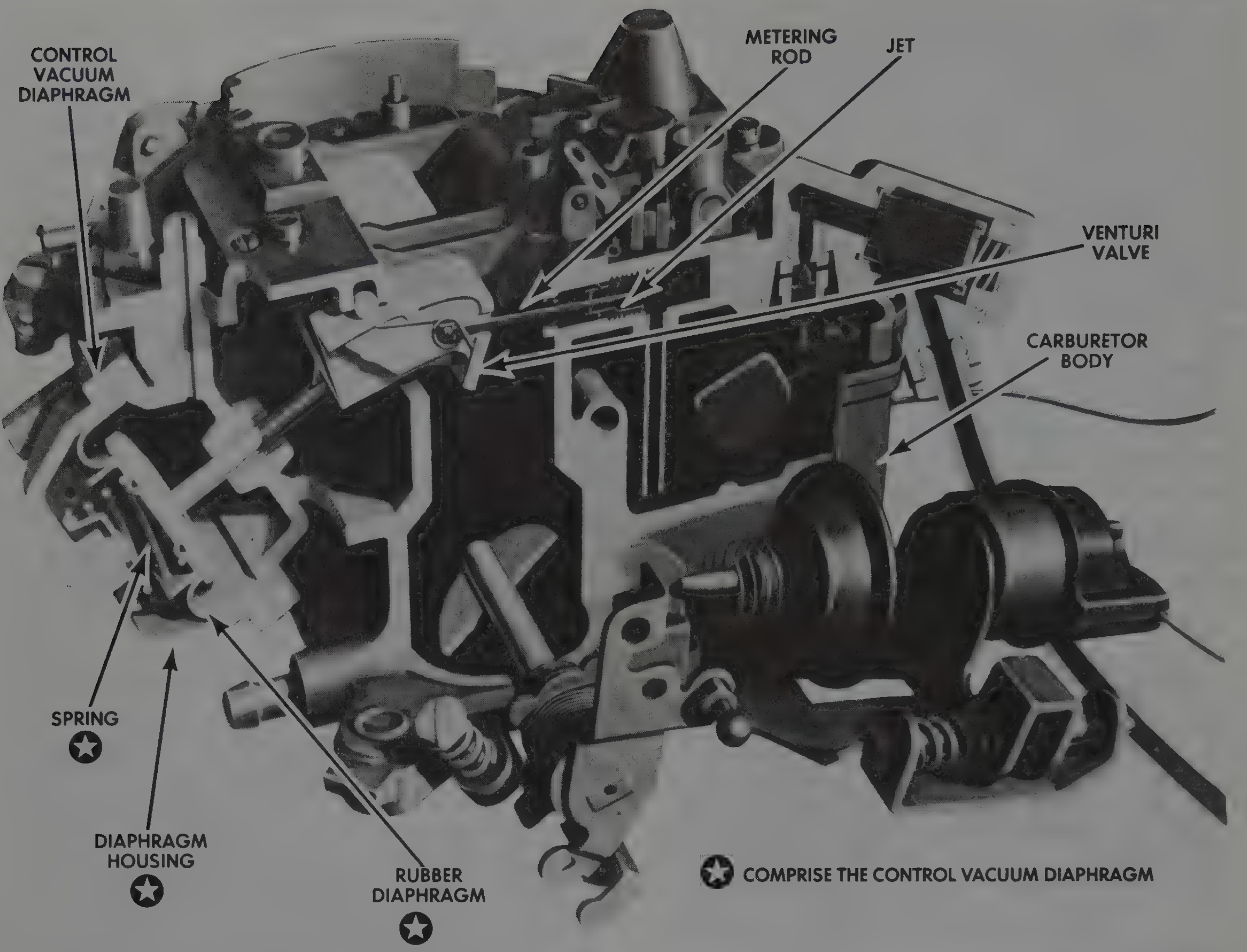

CONTROL VACUUM DIAPHRAGM
METERING ROD
JET
VENTURI VALVE
CARBURETOR BODY
SPRING ✪
DIAPHRAGM HOUSING ✪
RUBBER DIAPHRAGM ✪
✪ COMPRISE THE CONTROL VACUUM DIAPHRAGM

Figure 16-31. The variable venturi carburetor changes venturi size to meet different operating conditions. (Courtesy of Ford Motor Company)

FEEDBACK CARBURETORS

Some late-model vehicles have carburetors that incorporate an electronic *feedback system*. With this system, an oxygen sensor in the exhaust system detects the amount of oxygen in the exhaust gases. The electronic feedback system then calculates the required changes in the air-fuel mixture and moves the carburetor metering rod to change the mixture. Since this system was designed for emission control, it is described in more detail in Unit 20.

AIR CLEANERS

As discussed earlier in this unit, the engine uses much more air than fuel. The tremendous volume of air entering the engine must be cleaned to prevent abrasives from entering the engine and causing wear. All fuel systems use an **air cleaner**, or air filter, for this purpose.

The air cleaner is an assembly (Figure 16-32) that consists of an *air filter housing* with a paper or foam *filter element* inside the housing. Air enters the *snorkle* of the air filter housing, passes through the filter element and enters the carburetor. Dirt is trapped on the outside of the filter element.

A *vacuum motor* on the snorkle is used to direct heated air from a heat stove located on the *exhaust manifold* during warm-up. This function is described in more detail in Units 20, 21, and 22.

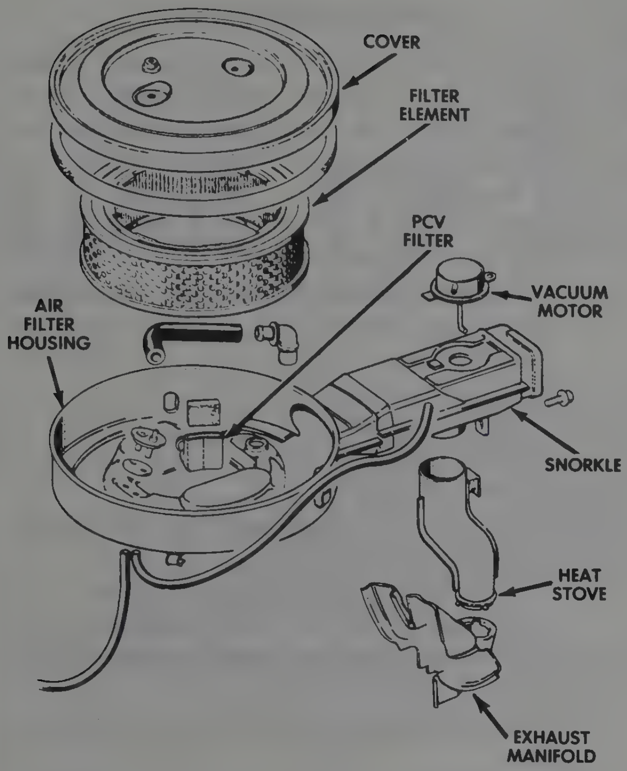


Figure 16-32. Exploded view of an air filter assembly. (Courtesy of American Motors Corporation)

KEY TERMS

Acceleration system: A system in the carburetor that provides a richer air-fuel mixture for acceleration.

Air bleed: Passages for air to enter the fuel in the carburetor.

Air cleaner: An assembly mounted above the carburetor to clean the air before it enters the engine.

Atomization: Breaking the liquid fuel into very small droplets.

Carburetor: Part of the fuel system that delivers a metered supply of fuel mixed with the correct amounts of air for efficient combustion in the cylinders.

Choke system: A system in the carburetor that provides a richer air-fuel mixture for cold starts.

Float system: A system in the carburetor that maintains a precise level of fuel.

Fuel filter: A device that removes foreign materials from the fuel on its way to the carburetor or fuel injector.

Fuel injector: A fuel-mixing device that injects the fuel directly into the cylinders or intake manifold. (See Unit 17 for details.)

Fuel lines: Lines that route fuel through the fuel system.

Fuel pump: A pump that makes a constant supply of fuel available at the carburetor.

Fuel tank: A tank used to store fuel in a vehicle.

Idle system: A system in the carburetor that provides the proper air-fuel mixture during engine idling and low-speed operation.

Intake manifold: A system of pipes that directs the air-fuel mixture into the intake ports in the cylinder head.

Low pressure: Any low pressure located above the throttle valve. (See **Manifold vacuum**)

Main metering system: A system in the carburetor that controls the middle, or cruising, range of the carburetor.

Manifold vacuum: Any low pressure located below the throttle valve. (See **Low pressure**)

Multiple-barrel carburetor: A carburetor with several small venturis and barrels.

Power system: A system in the carburetor that supplements the main metering system.

Throttle valve: A valve controlled by the throttle linkage that controls engine speed. Also called a throttle plate.

Vacuum: A pressure lower than atmospheric pressure.

Vaporization: Turning liquid fuel into a gas or vapor.

Variable venturi carburetor: A carburetor that is able to change the size of the venturi to maintain a sufficient air velocity and pressure drop for the main metering system.

Venturi: A constriction in the carburetor barrel.

SELF-CHECK

1. What is the purpose of the fuel system?
2. List the five basic parts of a fuel system.
3. What is the purpose of the restrictor assembly in the fuel tank filler neck?
4. Describe the operation of a rollover check valve in a vented filler cap.
5. Explain how a mechanical fuel pump works.
6. What are the two main parts of an electric fuel pump?
7. Why is a fuel filter necessary in a fuel system?
8. What is a venturi?
9. Why is fuel atomized and vaporized?
10. List the basic parts of a carburetor.
11. How does a carburetor float system work?
12. How does a carburetor idle system work?
13. How does a carburetor main metering system work?
14. How does a carburetor power system work?
15. Why is an acceleration system necessary in a carburetor?

DISCUSSION TOPICS AND ACTIVITIES

1. Use a cutaway of a carburetor to trace the flow of air and fuel through each carburetor system.
2. What is the relationship between intake manifold vacuum and fuel economy?

CERTIFICATION PRACTICE

1. Mechanic A says the carburetor power system is sensitive to engine RPM. Mechanic B says the power system is sensitive to manifold vacuum. Who is correct?
   A. Mechanic A
   B. Mechanic B
   C. Both Mechanics A and B
   D. Neither Mechanic A nor B
2. The electric fuel pump operation is controlled by an:
   A. Ignition switch
   B. Oil pressure switch
   C. Both A and B
   D. Neither A nor B
3. When the engine is being accelerated, the acceleration system:
   A. Provides a richer air-fuel mixture
   B. Provides a leaner air-fuel mixture
   C. Provides additional air
   D. None of the above
4. The main metering system directs fuel into the:
   A. Air horn
   B. Venturi
   C. Barrel
   D. Float bowl
5. The idle system directs air and fuel under the:
   A. Air horn
   B. Venturi
   C. Throttle valve
   D. Float bowl

ANSWERS

1: B, 2: C, 3: A, 4: B, 5: C

Unit 17

FUEL SYSTEM OPERATION — ELECTRONIC FUEL INJECTION SYSTEMS

The electronic fuel injection (abbreviated EFI) system is replacing the carburetion system in many vehicles. In an EFI system, fuel is injected directly into the engine's intake manifold. Electronic controls are used to sense engine operating conditions and then direct an exact amount of fuel to the intake valve ports. The EFI system is much more accurate than the carburetion system, resulting in higher fuel mileage and reduced exhaust emissions.

DEVELOPING JOB COMPETENCIES

When you finish reading and studying this unit, you should be able to:

- Explain the advantages of electronic fuel injection over carburetion.
- List the three general types of electronic fuel injection systems.
- Describe airflow, fuel flow, and electric controls for an airflow-sensitive timed EFI system.
- Explain the operation of a manifold pressure–sensitive timed EFI system.
- Describe the parts and operation of a continuous-flow EFI system.

ADVANTAGES OF ELECTRONIC FUEL INJECTION

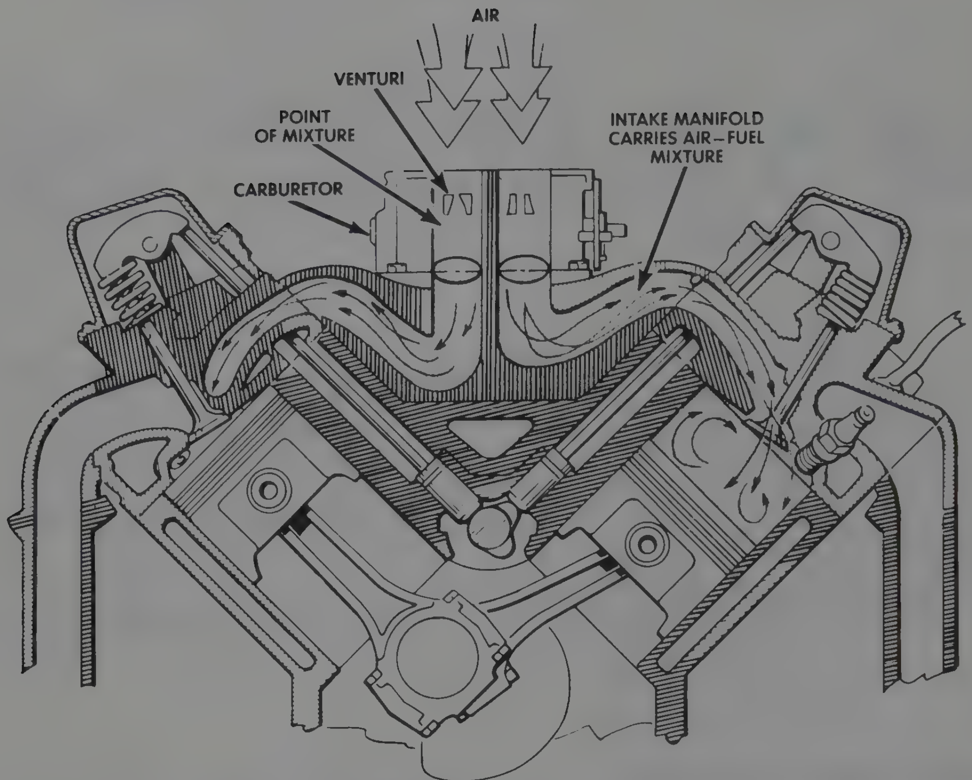
Refer to Figure 17-1 to compare and contrast the two types of fuel systems and note the advantages of the EFI system as follows:

In a *carburetion system* (Figure 17-1), air enters the top of the carburetor and is mixed with the fuel in the *venturi.* The air-fuel mixture is then moved through the *intake manifold* to the individual cylinders, where it is used for combustion.

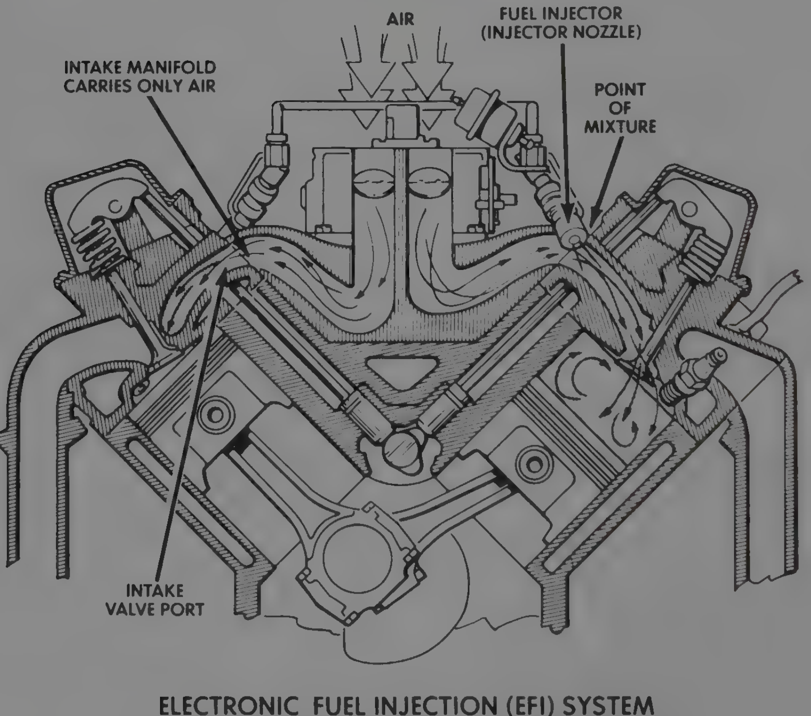
The main problem with the carburetion system is that the air-fuel mixture must flow around corners and through various shaped passages in the intake manifold to reach the cylinders. Fuel, being heavier than air, is hampered by curves and by the length of the intake manifold, so it tends to drop out of the air-fuel mixture. Consequently, some cylinders receive a richer mixture than others. The difference among cylinders may be as great as 15%.

In an *electronic fuel injection (EFI) system* (Figure 17-1), the intake manifold carries only air. The fuel is injected under pressure into the airflow by the *fuel injector,* also called an injector nozzle. The **fuel injector** is a fuel-mixing device that injects the fuel directly into the cylinders or the intake manifold at the *intake valve port.* An advantage over the carburetion system is that the intake manifold is not required to transport the air-fuel mixture. Since it does not have to perform this function, the intake manifold can be designed for the best breathing (airflow) possible.

Carburetor-equipped engines use an extra amount of fuel during cold operation to ensure that enough fuel is vaporized, mixed with the air, and carried to all of the cylinders. One of the most important advantages of the EFI


AIR
VENTURI
POINT OF MIXTURE
CARBURETOR
INTAKE MANIFOLD CARRIES AIR–FUEL MIXTURE

CARBURETION SYSTEM


AIR
FUEL INJECTOR (INJECTOR NOZZLE)
INTAKE MANIFOLD CARRIES ONLY AIR
POINT OF MIXTURE
INTAKE VALVE PORT

ELECTRONIC FUEL INJECTION (EFI) SYSTEM

Figure 17-1. Typical carburetion system and electronic fuel injection (EFI) system. (Courtesy of Chevrolet Motor Division, General Motors Corporation)

system is its ability to deliver equal amounts of fuel to all cylinders. Since the fuel is sprayed (injected) directly into a very warm part of the engine, less extra fuel is needed to obtain the proper air-fuel mixture needed in the combustion process.

In an EFI system, fuel is fed under pressure through a set of calibrated fuel injectors (one for each cylinder) so that the fuel discharged into each cylinder is equal. In a carburetion system, it is necessary to supply air-fuel mixtures rich enough that no cylinder will receive a mixture that is too lean. When richer air-fuel mixtures are introduced into cylinders which are already rich enough, this results in wasted fuel and creates excess hydrocarbons (HC) and carbon monoxide (CO). Any engine equipped with EFI can run leaner than one equipped with a carburetor.

In a carburetion system, the intake manifold must provide a medium between low-speed and high-speed requirements for airflow. At idle, airflow is very slight, and in order to keep the fuel mixed with the air, small intake manifold passages are necessary to maintain proper air velocity. However, when power is required, a large intake manifold passage is desirable to allow maximum breathing of the engine. To meet both of these requirements, the intake manifold design must be a compromise. The result is medium size intake manifold passages that permit acceptable low-speed and high-speed performance but limit both.

For most carburetors, the air-fuel mixture temperature is a problem during cold operation. It is therefore necessary to bring heat from the exhaust manifold up to the base of the carburetor during warm-up. This is accomplished via the heat riser passage. Unfortunately, the heat remains even when the engine is warm and the heat riser valve has opened. (See Unit 16, under the heading of "Intake Manifold," for additional information about the heat riser valve.) This often leads to vaporization problems and also requires periodic cleaning of the heat riser passage and heat riser valve. Electronic fuel injection, on the other hand, mixes the air and fuel in a very warm part of the engine, so very little extra heat is required during warm-up.

In an EFI system, response to open throttle is instantaneous, since the fuel is under pressure at all times and needs only to be released for acceleration. Since fuel delivery does not depend on the level of fuel in a float bowl, operation of an EFI system is not significantly affected by maneuvers such as tight turns and steep hill climbing. Also, there is no percolation (boiling) of fuel when the engine is hot, and the idle operation remains stable under panic stop situations. In addition, less fuel is required for the EFI system to operate at normal performance requirements.

The only significant disadvantage of EFI is cost. Its high cost compared to a carburetion system is the reason EFI is found mostly on more expensive vehicles. As stricter fuel mileage and emission control standards are imposed, however, EFI will probably become standard on even the least expensive vehicles.

TYPES OF ELECTRONIC FUEL INJECTION SYSTEMS

An optional fuel injection system was offered on at least one American automobile in the late 1950s and early 1960s. That system, however, was based on vacuum signals, rather than electronics. In the late 1950s, electronic fuel injection was developed and patented by the Bendix Corporation. At that time, electronic technology was still in the vacuum tube era, and EFI systems installed on cars experienced a high failure rate because of the severity of the automobile environment. With the evolution of solid state electronics, EFI systems greatly improved.

Three general types of EFI systems are in common use: *airflow-sensitive timed EFI, manifold pressure–sensitive timed EFI,* and *continuous-flow EFI.* Each will be described in the following sections.

Airflow-sensitive Timed EFI Systems

In an airflow-sensitive timed EFI system, a metered amount of fuel is injected into the intake manifold near the intake valves by electronically controlled *fuel injectors.* An airflow-sensitive timed EFI system has three subsystems: the *fuel flow system,* the *airflow system,* and the *electronic control system*. The basic parts of these subsystems and their typical location on an automobile are shown in Figure 17-2.

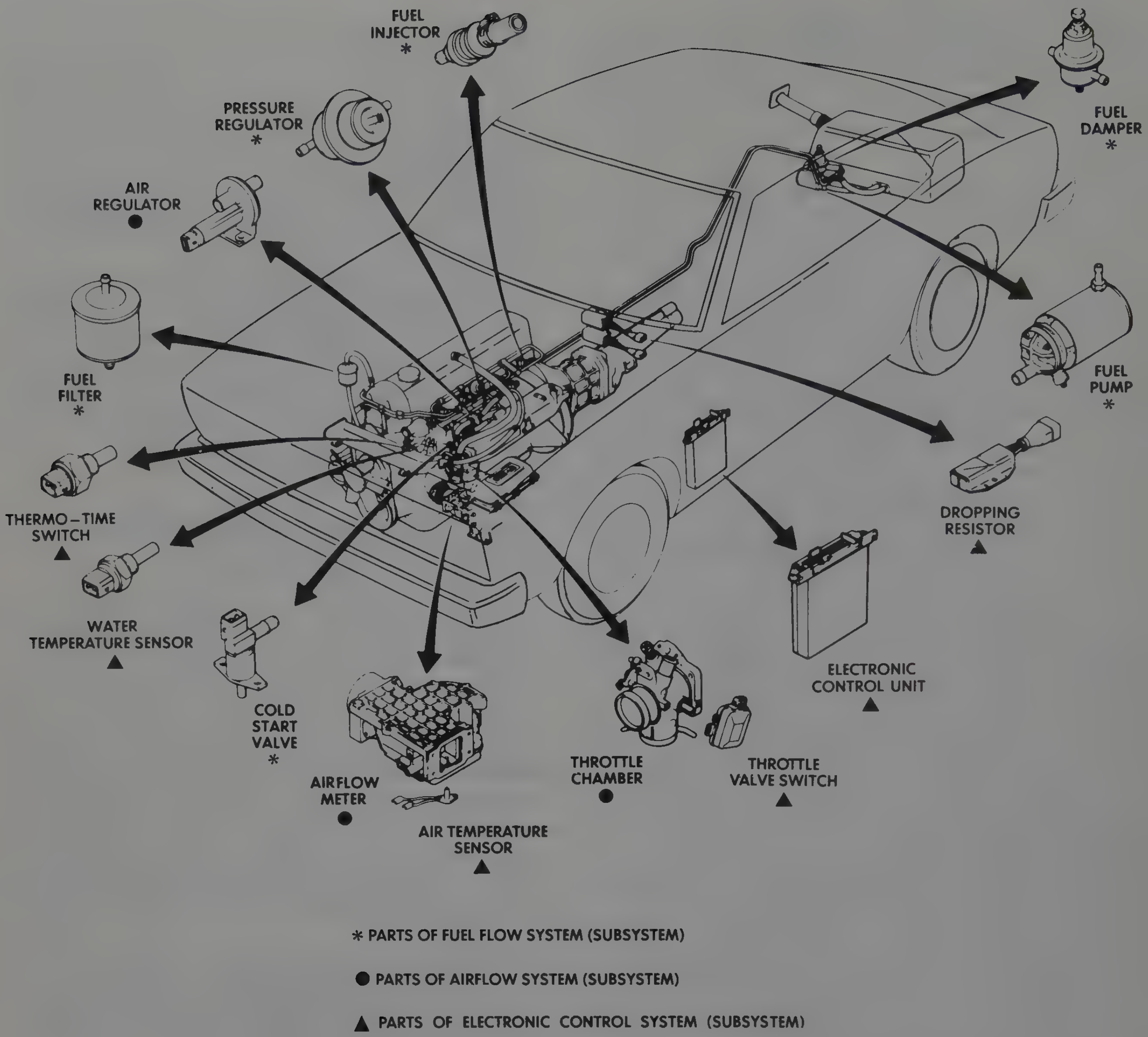

FUEL INJECTOR *
PRESSURE REGULATOR *
AIR REGULATOR ●
FUEL DAMPER *
FUEL FILTER *
FUEL PUMP *
THERMO-TIME SWITCH ▲
DROPPING RESISTOR ▲
WATER TEMPERATURE SENSOR ▲
COLD START VALVE *
ELECTRONIC CONTROL UNIT ▲
AIRFLOW METER ●
THROTTLE CHAMBER ●
THROTTLE VALVE SWITCH ▲
AIR TEMPERATURE SENSOR ▲
* PARTS OF FUEL FLOW SYSTEM (SUBSYSTEM)
● PARTS OF AIRFLOW SYSTEM (SUBSYSTEM)
▲ PARTS OF ELECTRONIC CONTROL SYSTEM (SUBSYSTEM)

Figure 17-2. Basic parts of an airflow-sensitive timed EFI system and their typical locations. (Courtesy of Nissan Motor Corporation in U.S.A.)

Fuel Flow System. The purpose of the **fuel flow system** is to provide the correct amount of fuel (gasoline) to each fuel injector. (A typical fuel flow system is shown in Figure 17-3.) Fuel is pulled from the fuel tank into the *fuel pump,* which discharges fuel under pressure. (The fuel pump, called a wet pump, is described in Unit 16, under the heading of "Fuel Pump.") As fuel flows through the *fuel damper,* pulsations in the fuel flow are *damped* (the pulsations are reduced). The fuel is then cleaned in the *fuel filter* and continues through the fuel line. It is injected (in a measured amount) into the intake manifold from the *fuel injector.*

Surplus fuel is led through the *pressure regulator* and is returned to the fuel tank. The

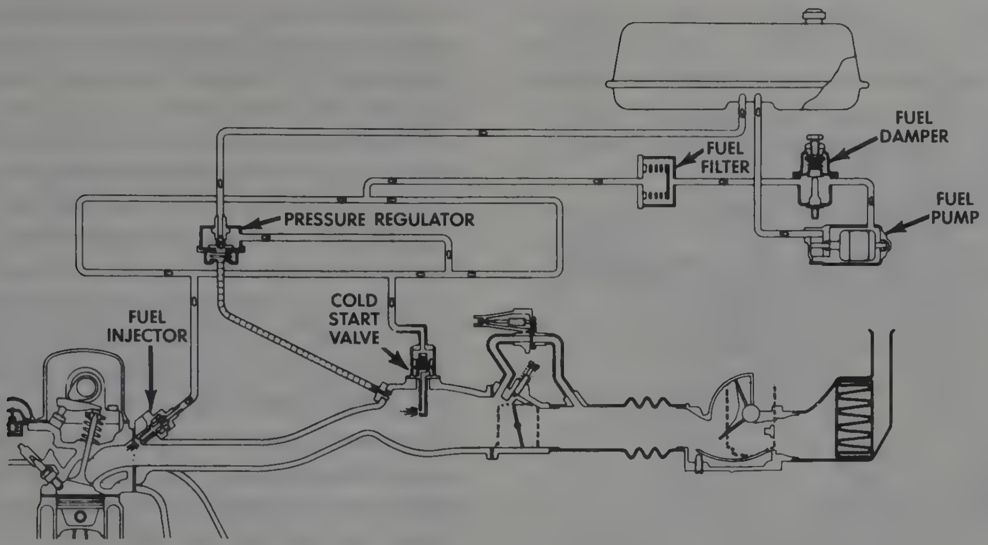

FUEL DAMPER
FUEL FILTER
FUEL PUMP
PRESSURE REGULATOR
COLD START VALVE
FUEL INJECTOR

Figure 17-3. Typical fuel flow system. (Courtesy of Nissan Motor Corporation in U.S.A.)

pressure regulator controls the injection pressure in such a manner that the pressure difference between the fuel pressure and the intake manifold vacuum is always 36.3 PSI. During starting, when the engine coolant temperature is below specifications, fuel is injected into the intake manifold from the *cold start valve.*

Fuel Damper. The purpose of the *fuel damper* (Figure 17-4) is to reduce pulsations, or surges, in the fuel flow discharged from the fuel pump. It is usually mounted next to the fuel pump and acts very much like a shock absorber. Fuel enters the *fuel chamber*, where a *diaphragm* is under *spring* pressure. If the fuel pump puts out pressure surges, then these surges push against the diaphragm and are absorbed by the spring. This eliminates the chance of these surges being present all the way to the fuel injectors. Thus, normal engine performance is maintained.

Fuel Filter. After the fuel leaves the fuel damper, it flows through a *fuel filter* (Figure 17-5). The filter is an assembly that allows fuel to flow through a *paper filter element* to trap foreign particles. The fuel filter is mounted in an accessible area of the engine compartment because it must be changed at regular intervals.

Filtered fuel flows to each of the fuel injectors—one for each cylinder. The fuel injectors are mounted on the intake manifold for each cylinder

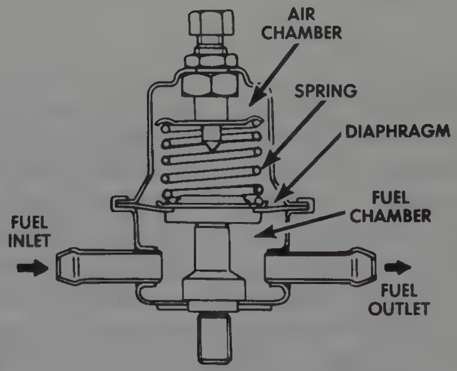

AIR CHAMBER
SPRING
DIAPHRAGM
FUEL CHAMBER
FUEL INLET
FUEL OUTLET

Figure 17-4. The fuel damper reduces pulsations in fuel discharged from the fuel pump. (Courtesy of Robert Bosch Sales Corporation)

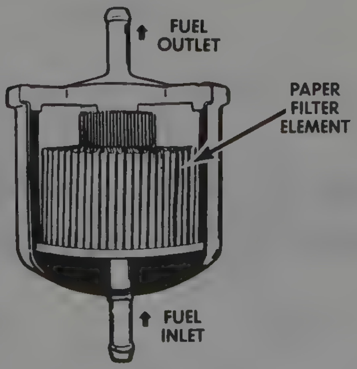

FUEL OUTLET
PAPER FILTER ELEMENT
FUEL INLET

Figure 17-5. The fuel passes through the fuel filter after it leaves the fuel damper. (Courtesy of Robert Bosch Sales Corporation)

(Figure 17-6). They are supported in a specially shaped molded rubber mount and are usually pressed, not screwed, into place. Since fuel flows directly to the fuel injectors, fuel pressure is available at the fuel injector at all times.

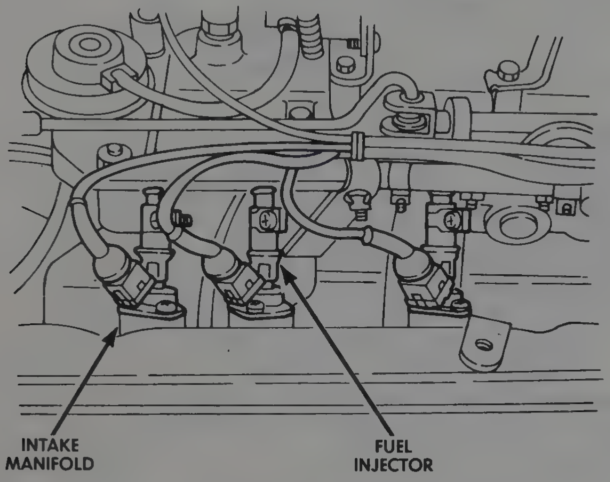


Figure 17-6. A fuel injector is mounted in the intake manifold for each cylinder. (Courtesy of Robert Bosch Sales Corporation)

Fuel Injector. The *fuel injector* (Figure 17-7) contains a small *solenoid* consisting of a *solenoid coil, solenoid plunger, spring,* and *final filter.* The final filter, mounted in the end of the *fuel supply line,* removes any contaminants from the fuel before it enters the fuel injector. The spring holds the *needle valve* in a closed position. When current is passed through the solenoid via the *electrical connector,* the needle valve is pulled from its seat, allowing fuel to be discharged. The length of time current is allowed to flow is regulated in milliseconds by the *electronic control unit* (discussed later in this unit). The time range is from 1.5 to 10 milliseconds (1/1000 of a second), depending on engine requirements.

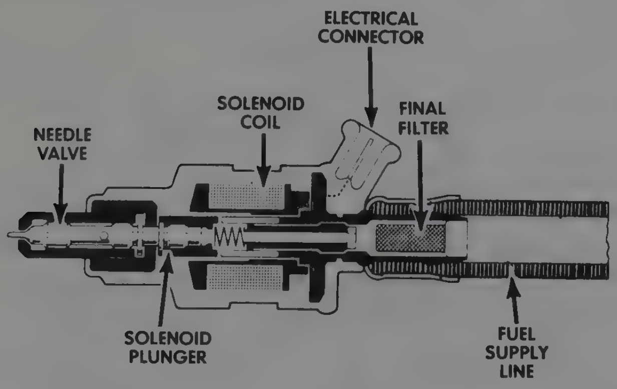


Figure 17-7. Cross section of a typical fuel injector. (Courtesy of Robert Bosch Sales Corporation)

The pressure of the fuel going to the fuel injectors is very important. If the pressure goes up, more fuel will be injected during a given period of time. If the pressure goes down, less fuel will be injected. Manifold vacuum also has an effect. If manifold vacuum becomes too high, more fuel will be sucked out of the fuel injectors. If manifold vacuum drops, less fuel will pass through the fuel injectors.

Pressure Regulator. Fuel pressure is controlled by a fuel *pressure regulator* (Figure 17-8). This regulator is usually mounted in the fuel line going to the fuel injectors or in the fuel line returning excess fuel to the fuel tank. In either case, its operation is the same.

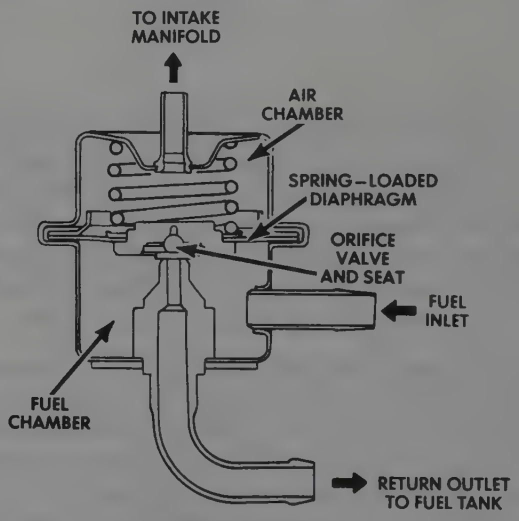


Figure 17-8. The pressure regulator controls pressure in the fuel system. (Courtesy of Robert Bosch Sales Corporation)

The pressure regulator is divided into an *air chamber* and *fuel chamber* by a *spring-loaded diaphragm.* Intake manifold vacuum is introduced into the air chamber, thereby keeping fuel pressure constant and causing excess fuel to return to the fuel tank through the return line. This is accomplished by the *orifice valve and seat* connected to the spring-loaded diaphragm. Movement of the spring-loaded diaphragm causes the orifice valve to open under excessive pressure, allowing the fuel to return to the fuel tank. As intake manifold vacuum increases, less fuel pressure is required by the fuel injectors. To compensate for this, a vacuum line is connected from the *intake manifold* to the pressure regulator valve. The manifold vacuum pulls on the spring-loaded diaphragm, resulting in lowered fuel pressure. Depending on intake manifold vacuum, fuel pressure may vary from 31 PSI at high manifold vacuum to 44 PSI at zero or low manifold vacuum.

Cold Start Valve. Like the carburetion system, the EFI system must provide more fuel to the engine for starting and for the warm-up period. A *cold start valve* (Figure 17-9) is used to provide this additional fuel. The cold start valve is actually an additional injector, mounted so that it can spray fuel into the airflow to the cylinders.

The cold start valve is an electromagnetic valve, which, electrically, is considered a solenoid. It has a *spring* that presses a movable *plunger* and *seal* against the *valve seat.* This blocks the flow of fuel.

When the plunger and seal are drawn back, the valve seat opens and fuel flows along the sides of the plunger to the *swirl nozzle.* In the swirl nozzle, a swirling motion is imparted to the fuel, and the fuel leaves the swirl nozzle in a finely atomized state.

The operation of the cold start valve is controlled by the *thermo-time switch,* which is discussed in detail under the heading of "Electronic Control System" in this unit.

Airflow System. The purpose of the **airflow system** is to provide for the flow of air into the engine. (A typical airflow system is shown in Figure 17-10.) The amount of airflow is measured, and that measurement is used to determine the amount of fuel injected.

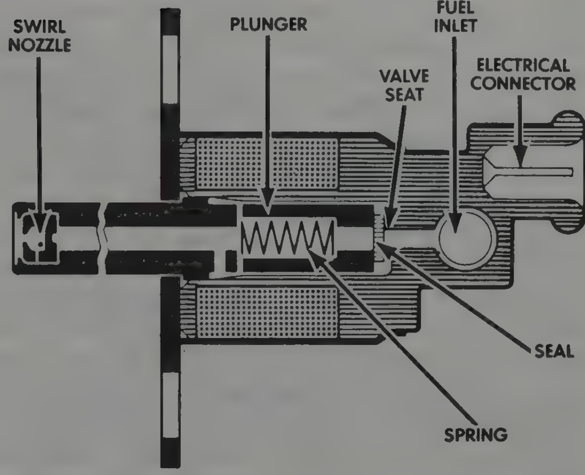


Figure 17-9. The cold start valve is an additional injector that provides extra fuel for cold starting. (Courtesy of Robert Bosch Sales Corporation)

Intake air from the *air filter* is metered through the *airflow meter*, through the *throttle chamber*, and into the *intake manifold*. It then flows through each intake manifold branch into the cylinders. Airflow while driving is controlled by the *throttle valve* located in the throttle chamber. During idling operation, the throttle valve is in its almost closed position, and the air is led through the *bypass port* mounted on the throttle chamber. In this case, the quantity of suction air is adjusted by means of the *idle speed adjusting screw*. During warm-up operation, the airflow is bypassed through the *air regulator* to increase engine RPM.

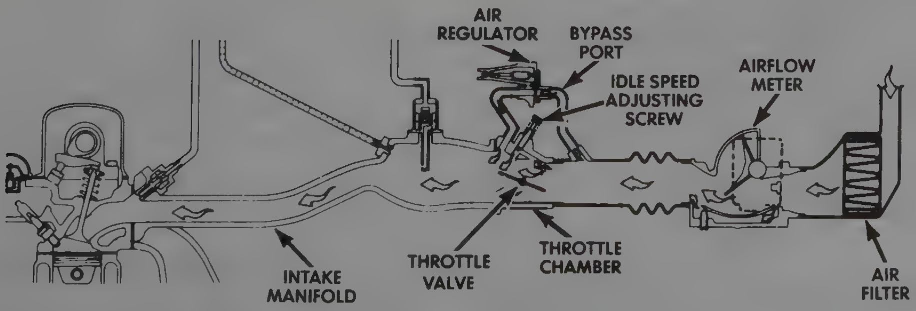


Figure 17-10. Typical airflow system. (Courtesy of Nissan Motor Corporation in U.S.A.)

Airflow Meter. The heart of the airflow system is the *airflow meter* (Figure 17-11). The primary purpose of the airflow meter is to furnish the *electronic control unit* (part of the electronic control system, which is covered later in this unit) with a *voltage signal* concerning the rate of airflow. The airflow is measured as follows:

A *baffle plate* fitted in the meter and attached to a *return spring* is mechanically connected to a *potentiometer*, which converts the baffle plate position into an electric voltage signal sent to the control unit. By using a *compensating flap* and *compensating chamber*, a dampening effect is exerted on the baffle plate. This feature reduces the effect of any airflow pulsations and results in smoother operation of the baffle plate. To eliminate any possible damage to the airflow meter from engine backfire, a *back-pressure relief valve* is built into the baffle plate. A *bypass channel* is also built into the airflow meter. The bypass channel air is not measured by the airflow meter, but it is used to set the air-fuel mixture at idle. An *idle mixture screw,* also called an *air bypass screw*, is provided in the airflow meter for this purpose (Figure 17-12).

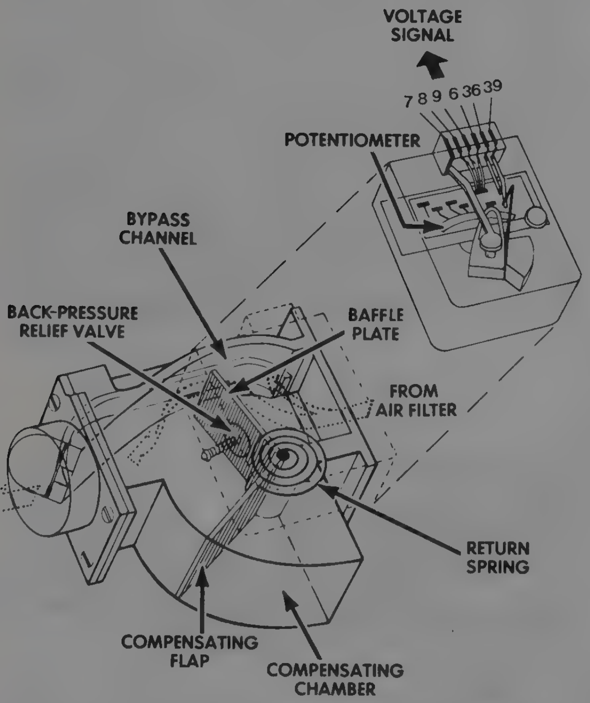

VOLTAGE SIGNAL
7 8 9 6 36 39
POTENTIOMETER
BYPASS CHANNEL
BACK-PRESSURE RELIEF VALVE
BAFFLE PLATE
FROM AIR FILTER
RETURN SPRING
COMPENSATING FLAP
COMPENSATING CHAMBER

Figure 17-11. The airflow meter controls the amount of air entering the engine and sends a voltage signal to the control unit. (Courtesy of Robert Bosch Sales Corporation)

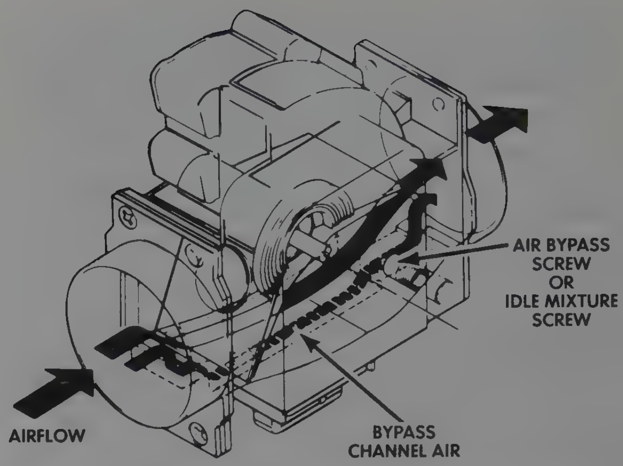
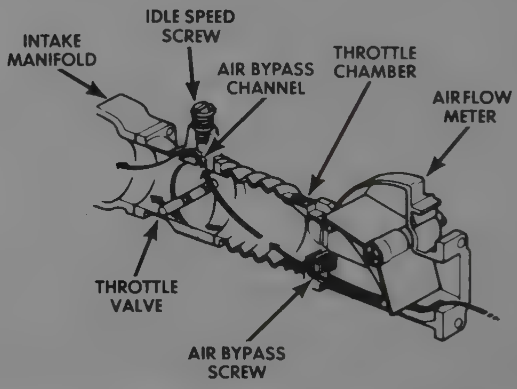
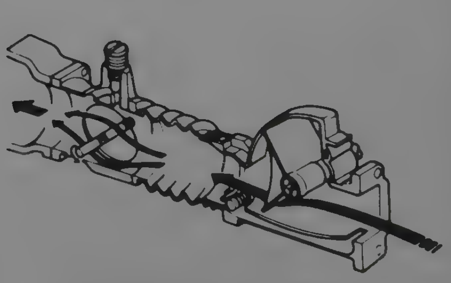

AIR BYPASS SCREW OR IDLE MIXTURE SCREW
AIRFLOW
BYPASS CHANNEL AIR

Figure 17-12. The air bypass screw or idle mixture screw regulates the bypass channel air. (Courtesy of Nissan Motor Corporation in U.S.A.)

Throttle Chamber. Mounted between the *intake manifold* and the *airflow meter* is an assembly called the *throttle chamber* (Figure 17-13). The *throttle valve* of the throttle chamber is mechanically connected to the accelerator linkage. The throttle chamber also incorporates an idle air bypass channel (for airflow into the intake


IDLE SPEED SCREW
INTAKE MANIFOLD
AIR BYPASS CHANNEL
THROTTLE CHAMBER
AIRFLOW METER
THROTTLE VALVE
AIR BYPASS SCREW

THROTTLE VALVE CLOSED (IDLING)



THROTTLE VALVE OPEN

Figure 17-13. Operation of the throttle valve in the opened and closed position. (Courtesy of Nissan Motor Corporation in U.S.A.)

manifold when the throttle valve is closed). An *idle speed screw* regulates the amount of bypass air around the closed throttle valve. This provides a fast idle system during engine warm-up. The *electronic control unit* reacts to this additional air by metering an additional amount of fuel. As a result, more air-fuel mixture is available to the engine for the warm-up period.

Air Regulator. The component that regulates the additional air is the *air regulator* (Figure 17-14), sometimes referred to as an *auxiliary air valve.* It is similar to an electric choke in that it has a *heating element*. It also contains a *slotted disc* that rotates to open, close, or partially close the air passage. The position of the slotted disc is controlled by a *bimetal spring*. When cold, the slotted disc is open. It closes progressively as it is heated. The bimetal spring is heated by the heating element, which receives current whenever the engine is running. When the slotted disc reaches a temperature of approximately 158° F, it closes completely.

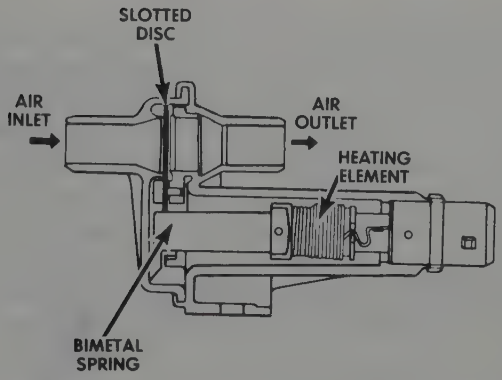

SLOTTED DISC
AIR INLET
AIR OUTLET
HEATING ELEMENT
BIMETAL SPRING

Figure 17-14. The air regulator provides for fast idle during engine warm-up. (Courtesy of Robert Bosch Sales Corporation)

Electronic Control System. The purpose of the **electronic control system** is to sense engine operating conditions and to regulate the quantity of fuel injected in relation to airflow. Figure 17-15 shows a typical wiring diagram for an electronic control system for an

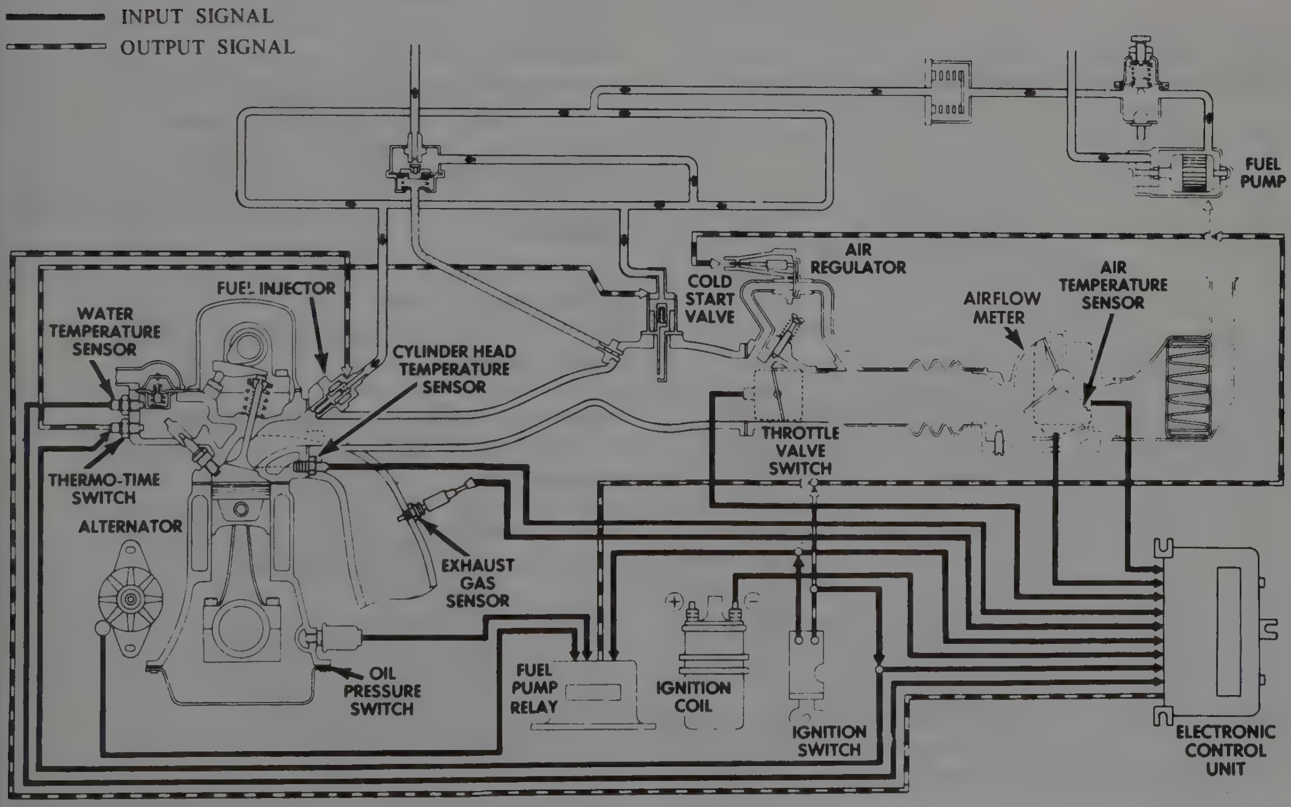
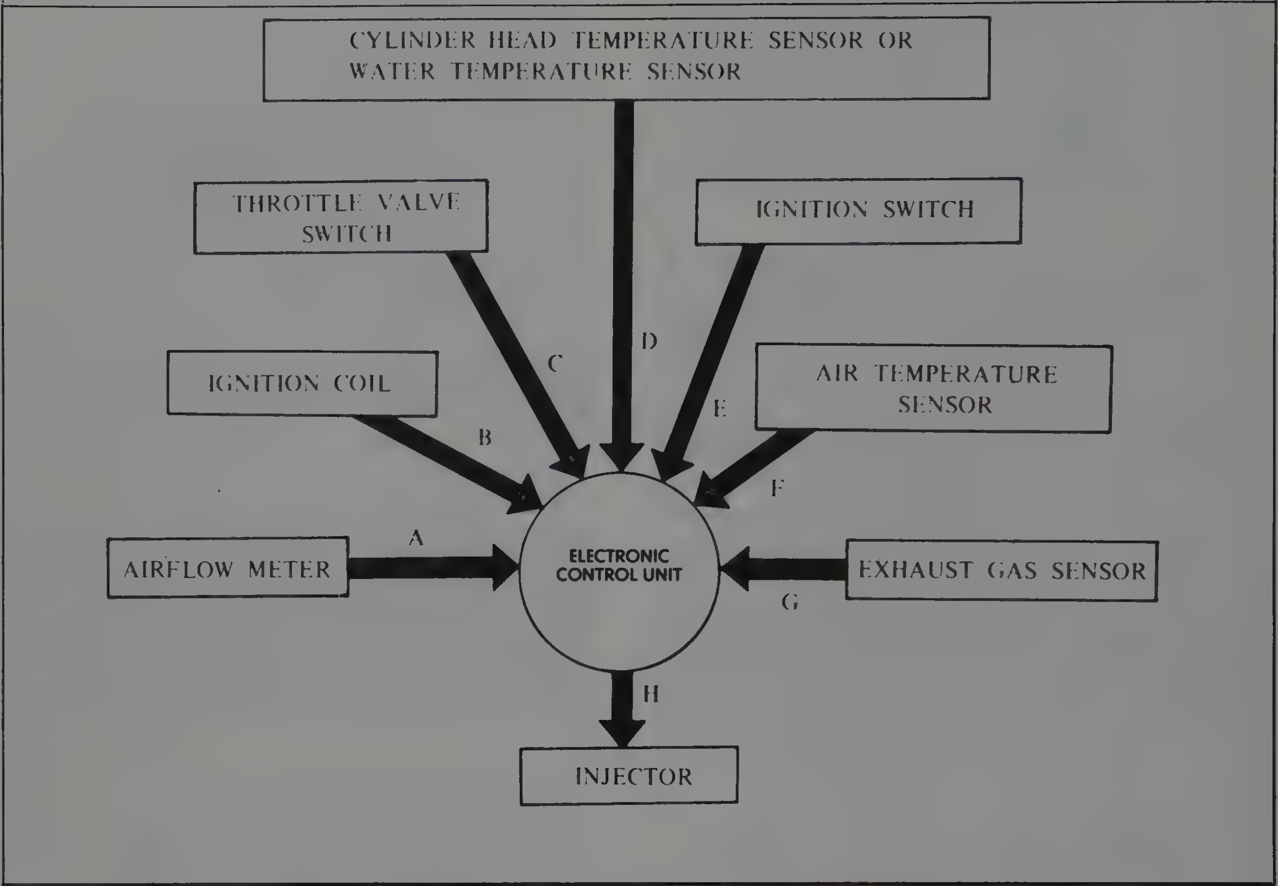

INPUT SIGNAL
OUTPUT SIGNAL
FUEL PUMP
AIR REGULATOR
COLD START VALVE
AIR TEMPERATURE SENSOR
AIRFLOW METER
FUEL INJECTOR
WATER TEMPERATURE SENSOR
CYLINDER HEAD TEMPERATURE SENSOR
THROTTLE VALVE SWITCH
THERMO-TIME SWITCH
ALTERNATOR
EXHAUST GAS SENSOR
OIL PRESSURE SWITCH
FUEL PUMP RELAY
IGNITION COIL
IGNITION SWITCH
ELECTRONIC CONTROL UNIT

Figure 17-15. Typical wiring diagram for an electronic control system for an airflow-sensitive timed EFI. (Courtesy of Nissan Motor Corporation in U.S.A.)


CYLINDER HEAD TEMPERATURE SENSOR OR WATER TEMPERATURE SENSOR
THROTTLE VALVE SWITCH
IGNITION SWITCH
IGNITION COIL
AIR TEMPERATURE SENSOR
AIRFLOW METER
ELECTRONIC CONTROL UNIT
EXHAUST GAS SENSOR
INJECTOR
A
B
C
D
E
F
G
H

Signal		Device	Item to be monitored or actuated
Input	A	Airflow meter	Quantity of intake air
	B	Ignition coil negative terminal	Engine rpm
	C	Throttle valve switch	Opening of throttle valve ("full" and "after idle" enrichment, and fuel shut-off operation during coasting)
	D	Cylinder head temperature sensor or water temperature sensor	Temperature of engine ("warm-up", "after start" and "after idle" enrichment, and fuel shut-off operation during coasting)
	E	Ignition switch "START" position	Starting operation ("start" and "after start" enrichment)
	F	Air temperature sensor	Temperature of intake air ("intake air temperature" enrichment)
	G	Exhaust gas sensor	Density of oxygen in exhaust gases
Output	H	Fuel Injector	Fuel injects into intake manifold

Figure 17-16. Sensors provide the control unit with data which are used to control electronic injection pulses. (Courtesy of Nissan Motor Corporation in U.S.A.)

airflow-sensitive timed EFI system. As discussed earlier in this unit, the fuel flow system delivers a constant fuel pressure to the fuel injectors. The area of the fuel injector nozzle hole is constant. Neither of these factors (fuel pressure and fuel injector nozzle hole area) affect fuel injection quantity. The fuel injectors' **pulse time**, sometimes called *open-valve time*, regulates fuel injection quantity as it changes. Pulse time is the time in which the fuel injectors are open and providing fuel. It is measured in milliseconds. (One millisecond represents one thousandth of a second.) The average maximum pulse time for an airflow-sensitive timed EFI system is about 10 milliseconds. Pulse time is determined from various sensors (Figure 17-16).

An electrical signal from each sensor is sent to the *electronic control unit* for processing and response. The pulse time period of the fuel injectors is then determined by the electronic control unit.

Electronic Control Unit. Information on the quantity of the air drawn into the engine, the engine's coolant and cylinder head temperatures, the position of the throttle valve, the vehicle starting process, the engine's speed, the start of fuel injection, and the oxygen in the exhaust gas is received by the *electronic control unit* (Figure 17-17). It processes this information and transmits signals to the various electrical components of the airflow-sensitive timed EFI system by means of a multiple-pin plug and wiring harness.

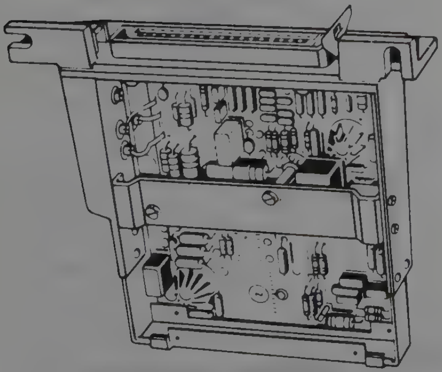


Figure 17-17. Typical electronic control unit used to process sensor information and send out a signal for appropriate response. (Courtesy of Robert Bosch Sales Corporation)

Thermo-time Switch. The electric circuit leading to the *cold start valve* is closed and opened by the *thermo-time switch* (Figure 17-18). It is usually mounted next to the cooling system's thermostat housing, and its operation depends on engine temperature. This means that the cold start valve, which is part of the fuel flow system, is activated (turned on) only at engine temperatures below a specific level. Depending on engine type, this level is generally (but not always) below 60° F.

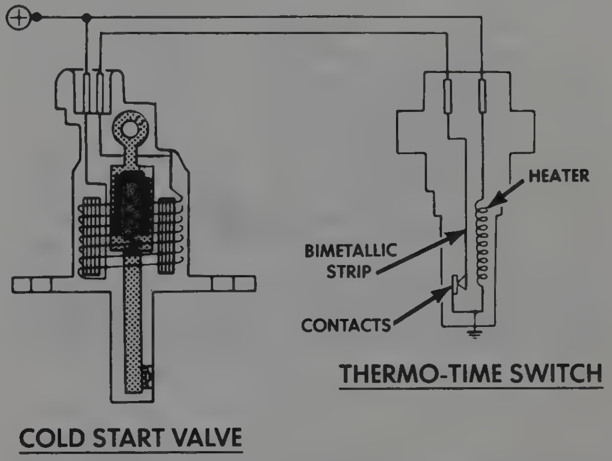


Figure 17-18. The thermo-time switch controls the operation of the cold start valve. (Courtesy of Robert Bosch Sales Corporation)

The thermo-time switch also limits the time during which the cold start valve is activated. An electrically heated *bimetallic strip* interrupts the electric circuit powering the cold start valve. At coolant temperatures below 60° F, the thermo-time switch is on. At coolant temperatures higher than 60° F, it is off.

The bimetallic strip functions with a *heater.* Current flows through the heater while the ignition switch is in the START position. This warms up the bimetallic strip through repeated operation of the ignition switch. Then the bimetallic strip is sufficiently warmed up to open its *contacts.* This stops current flow to the cold start valve and thus prevents excessive injection of fuel, which could lead to problems in engine operation.

Water Temperature Sensor. Built into the thermostat housing is a *water temperature sensor* (Figure 17-19). It monitors changes in coolant temperature and transmits a signal for fuel enrichment change in the time pulse duration during the warm-up period. It uses a *thermistor* (a semiconductor component) that is very sensitive in the low temperature range. The electrical resistance of the thermistor decreases in response to any coolant temperature rise.

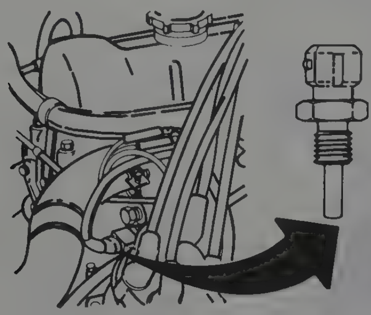


Figure 17-19. The water temperature sensor is located in the thermostat housing of the cooling system. (Courtesy of Nissan Motor Corporation in U.S.A.)

Cylinder Head Temperature Sensor. Built into the cylinder head is a *cylinder head temperature sensor* (Figure 17-20). It monitors change in cylinder head temperature and transmits a signal for fuel enrichment change in the pulse time duration during the warm-up period.

Air Temperature Sensor. Built into the airflow meter is an *air temperature sensor* (Figure 17-21). It monitors changes in the intake air temperature and transmits a signal for fuel enrichment change in the pulse time duration.

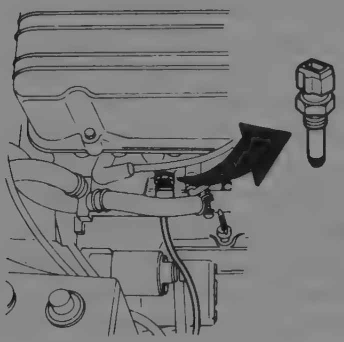


Figure 17-20. The cylinder head temperature is monitored by the cylinder head temperature sensor (see arrow). (Courtesy of Nissan Motor Corporation in U.S.A.)

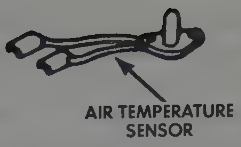


Figure 17-21. Typical air temperature sensor that monitors changes in the intake air temperature. (Courtesy of Nissan Motor Corporation in U.S.A.)

Throttle Valve Switch. Attached to the throttle chamber is a *throttle valve switch* (Figure 17-22). It actuates in response to accelerator pedal movement. This switch has two sets of contact points: *idle contact points* and *full throttle contact points.*

The idle contact points close when the throttle valve is positioned at idle and open when it is at any other position. This compensates for idle and after-idle enrichment and sends the fuel shut-off signal.

The full throttle contact points close only when the throttle valve is positioned at full throttle (more than 34° opening of the throttle valve). They open when the throttle valve is at any other position. The full throttle contact points compensate for enrichment in full throttle position.

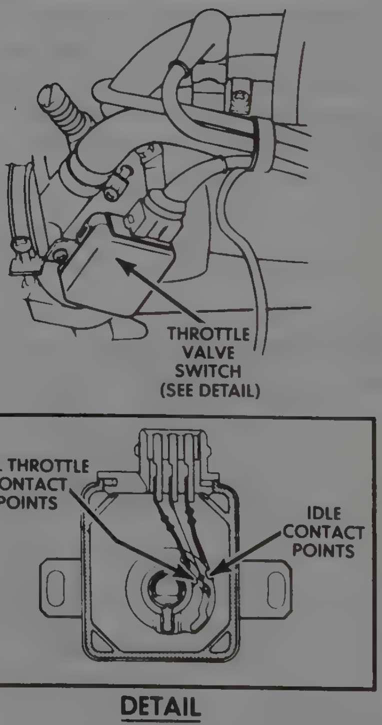

THROTTLE VALVE SWITCH (SEE DETAIL)
FULL THROTTLE CONTACT POINTS
IDLE CONTACT POINTS
DETAIL

Figure 17-22. The throttle valve switch senses throttle position. (Courtesy of Nissan Motor Corporation in U.S.A.)

Oxygen Sensor. Most late-model fuel injection systems use a feedback signal from an *oxygen sensor* located in the *exhaust manifold* (Figure 17-23). (This arrangement is referred to as a *feedback system* and is covered in Unit 20.) The oxygen sensor is used to monitor the air-fuel mixture and to send a signal to the electronic control unit when ratio changes are necessary. The average air-fuel mixture for full combustion is called the *stoichiometric air-fuel ratio* (about 15 to 1). The oxygen sensor is calibrated to the theoretically perfect air factor for this ratio. The perfect air factor is called *lambda*, so the oxygen sensor is often called **a lambda probe.**

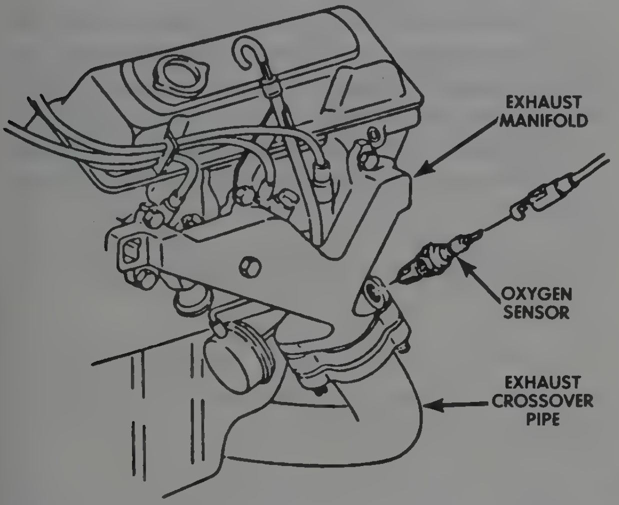

EXHAUST MANIFOLD
OXYGEN SENSOR
EXHAUST CROSSOVER PIPE

Figure 17-23. An oxygen sensor located in the exhaust manifold monitors the air-fuel ratio. (Courtesy of Chevrolet Motor Division, General Motors Corporation)

The parts of the oxygen sensor are shown in Figure 17-24. It utilizes the *oxygen concentration cell principle* to produce voltage by means of the oxygen density difference in the exhaust gas. A thin layer of *platinum* is bonded to both surfaces (atmosphere side and exhaust side) of the test tube–shaped *zirconia element*. The exhaust side also has a *ceramic coating*. Atmospheric air is directed to the inner surface or atmospheric side while the outer surface or exhaust side is exposed to the exhaust gas. The voltage signal is sent to the electronic control unit.

If there is an oxygen density difference between the surfaces of the zirconia element, it will produce voltage. If the air-fuel ratio is leaner than the theoretically perfect air-fuel ratio, the voltage signal will be low; if it is richer, the voltage signal will be high. This results in a *closed loop* — that is, the system itself can monitor whether the specified air-fuel mixture actually results in combustion that emits exhaust gas low in emissions. If the air-fuel mixture deviates from the specified value, this is sensed by the oxygen sensor on the basis of the leftover oxygen concentration in the exhaust gas, and this condition is made known to the electronic control unit by a voltage signal. The electronic control unit processes the voltage signal to change the duration of injection and thus corrects the air-fuel mixture.

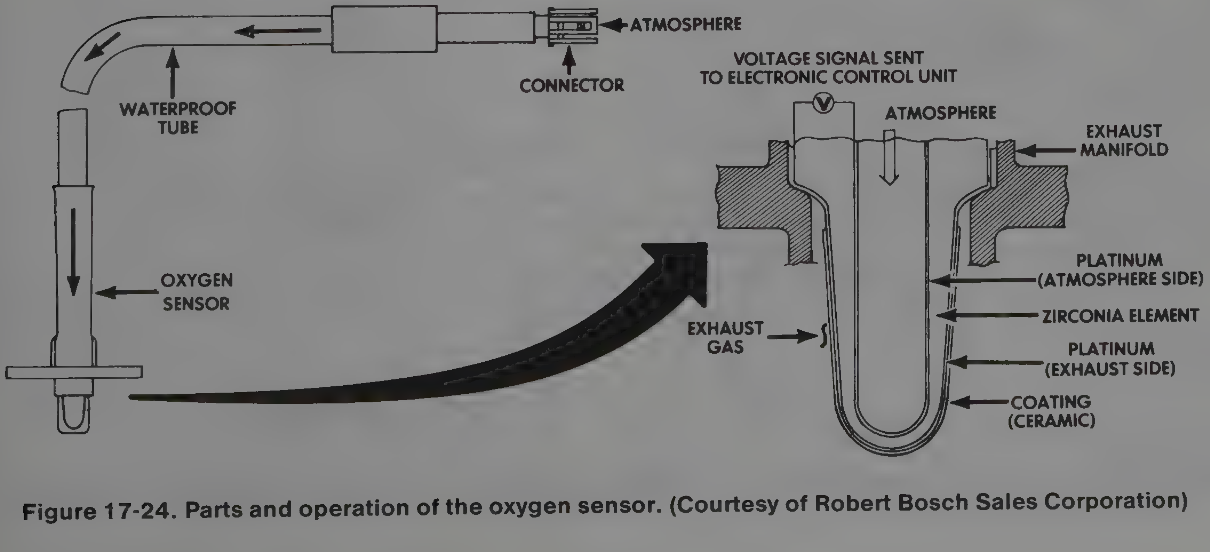

ATMOSPHERE
CONNECTOR
WATERPROOF TUBE
OXYGEN SENSOR
VOLTAGE SIGNAL SENT TO ELECTRONIC CONTROL UNIT
V
ATMOSPHERE
EXHAUST MANIFOLD
PLATINUM (ATMOSPHERE SIDE)
ZIRCONIA ELEMENT
EXHAUST GAS
PLATINUM (EXHAUST SIDE)
COATING (CERAMIC)

Figure 17-24. Parts and operation of the oxygen sensor. (Courtesy of Robert Bosch Sales Corporation)

Dropping Resistor. The purpose of the *dropping resistor* (Figure 17-25) is to lower the voltage delivered to the fuel injector. It is connected in series with the fuel injector and reduces the voltage at the fuel injector to about one-fourth of the source voltage (alternator or battery).

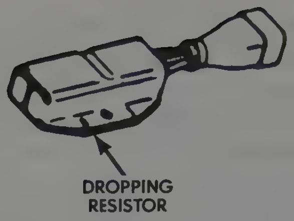

DROPPING RESISTOR

Figure 17-25. Typical dropping resistor used to lower the voltage delivered to the fuel injector. (Courtesy of Nissan Motor Corporation in U.S.A.)

Fuel Injection Control

It is possible to design an electronic fuel injection system so that each fuel injector injects its fuel when its cylinder is ready for an intake stroke. However, such a design would make the system too complex. Therefore, instead, all the fuel injectors are connected electrically parallel so that half of the required amount of fuel is injected during each crankshaft revolution and at the same time. This simplifies the electronic circuitry in the electronic control unit.

The required fuel quantity is attained after fuel injection occurs twice during one cycle (intake, compression, power, and exhaust). In other words, one injection of fuel provides only half the fuel quantity necessary for operation of one cycle of the engine.

Fuel in this system is not injected directly into the cylinder but is injected just behind the intake valve. The air-fuel mixture is pulled into the cylinder when the intake valve opens to start the intake stroke. In other strokes, the air-fuel mixture is kept behind the closed intake valve.

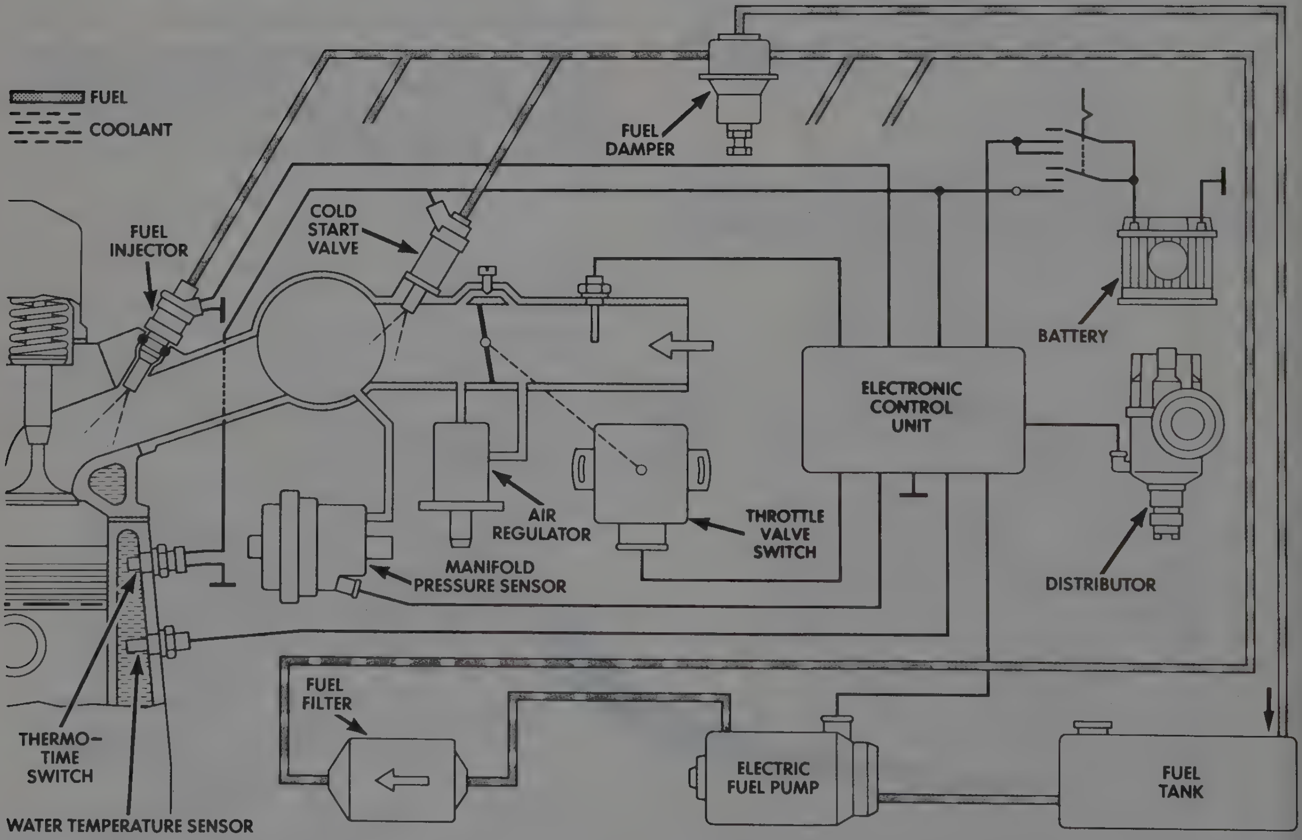

FUEL
COOLANT
FUEL DAMPER
FUEL INJECTOR
COLD START VALVE
BATTERY
ELECTRONIC CONTROL UNIT
AIR REGULATOR
THROTTLE VALVE SWITCH
MANIFOLD PRESSURE SENSOR
DISTRIBUTOR
FUEL FILTER
THERMO-TIME SWITCH
ELECTRIC FUEL PUMP
FUEL TANK
WATER TEMPERATURE SENSOR

Figure 17-26. A manifold pressure-sensitive timed EFI system using a manifold pressure sensor. (Courtesy of Robert Bosch Sales Corporation)

Manifold Pressure–sensitive Timed EFI System

The manifold pressure–sensitive timed EFI system (Figure 17-26) has the same basic parts as the airflow-sensitive timed EFI system except that it does not use an airflow meter. Instead, it uses a *manifold pressure sensor* to determine engine airflow. The manifold pressure sensor is installed in a sealed metal housing which is connected to the intake manifold of the engine.

The operation of the manifold pressure sensor is shown in Figure 17-27. It contains two *diaphragm cells,* which move an *armature* inside a *coil* when the engine is under a load or the throttle valve is open. As the pressure in the intake manifold decreases, the diaphragm cells are pressed together, and the armature is drawn farther into the coil. As a result, the inductance of the coil increases. The manifold pressure sensor converts a pneumatic (air) signal into an electrical signal. The *inductive pickup* in the manifold pressure sensor is connected to a timer in the electronic control unit. This timer determines the duration of the electric pulses (signals) which are transmitted to the fuel injectors. In this way, the intake manifold pressure is converted directly into the corresponding duration of fuel injection (pulse time).

When the throttle valve is closed, the intake manifold pressure is high. As a result, the diaphragm cells are pressed less firmly together, and they slide the armature out of the coil. The inductance of the coil is thus lowered, the time pulse becomes shorter, and the fuel injectors discharge less fuel.

Continuous-flow EFI System

The continuous-flow EFI system, commonly referred to as CIS, is different from the airflow-sensitive and manifold pressure-sensitive timed EFI systems in that fuel is being injected constantly while the engine is running. CIS is a relatively simple system and therefore has fewer parts than any other EFI system in general use. The fuel injectors in this system are not electrically pulsed but are activated by fuel pressure.

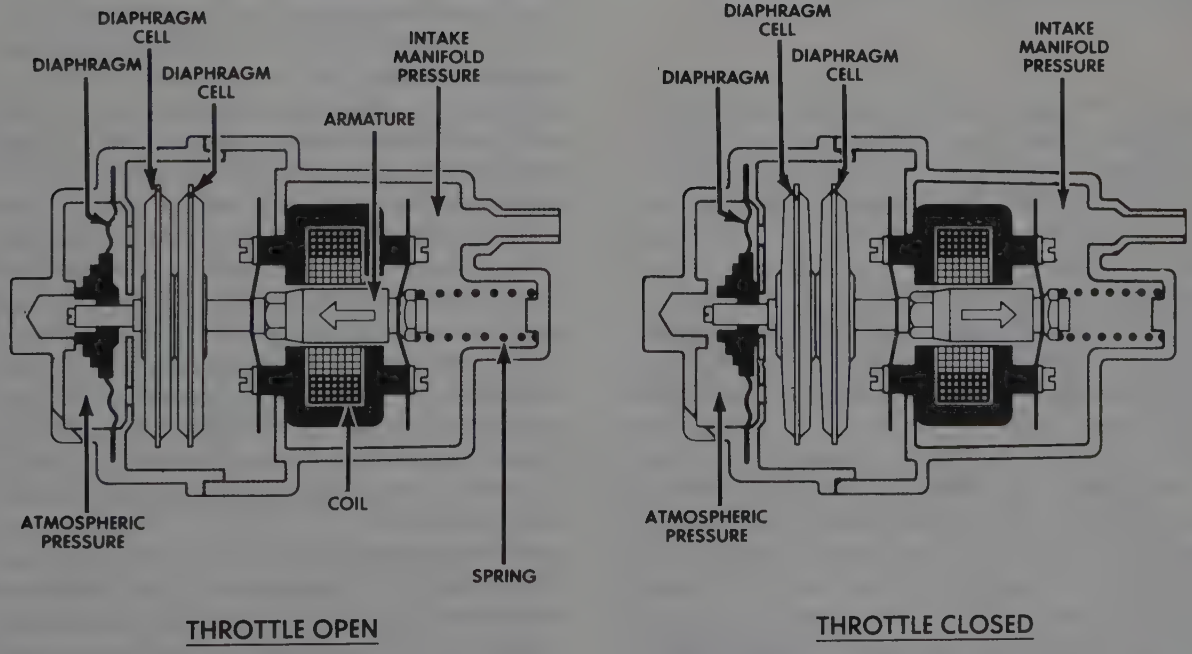

DIAPHRAGM CELL
DIAPHRAGM
DIAPHRAGM CELL
INTAKE MANIFOLD PRESSURE
ARMATURE
ATMOSPHERIC PRESSURE
COIL
SPRING
THROTTLE OPEN
DIAPHRAGM CELL
DIAPHRAGM
DIAPHRAGM CELL
INTAKE MANIFOLD PRESSURE
ATMOSPHERIC PRESSURE
THROTTLE CLOSED

Figure 17-27. Operation of the manifold pressure sensor. (Courtesy of Robert Bosch Sales Corporation)

The continuous-flow EFI system uses basically the same type of components as the other EFI systems. The main difference is an *airflow sensor*, which is connected mechanically to a *fuel distributor* (Figure 17-28).

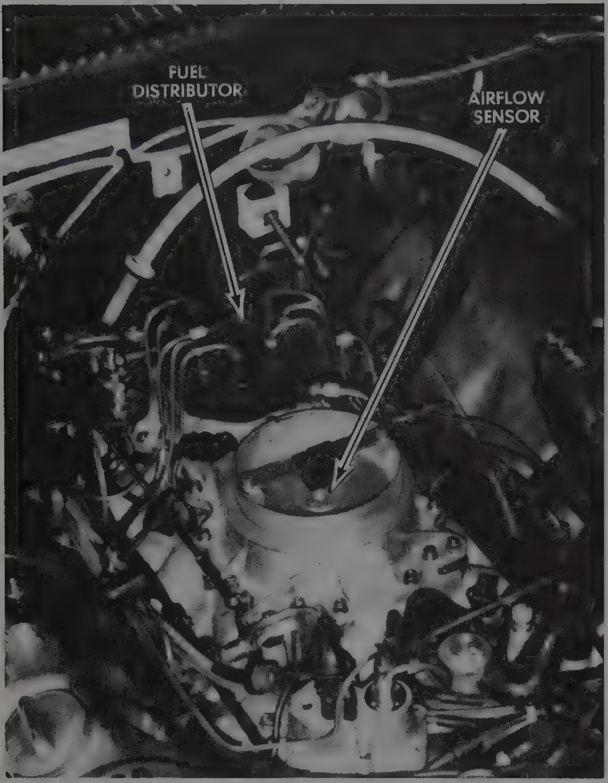


Figure 17-28. The continuous-flow EFI system has an airflow sensor connected to a fuel distributor.

Airflow Sensor. The airflow sensor (Figure 17-29) utilizes an *air funnel* and an *airflow sensor plate* mounted on a *lever* which is supported on a *pivot*. The weight of the lever and airflow sensor plate is balanced by a *counterweight*. A plunger called the *control plunger* operates under fuel pressure and transmits its force to oppose the force of the airflow on the lever and airflow sensor plate. The intake air flows through the air funnel and lifts the airflow sensor plate until the force of this air and the opposing force of the control plunger are equal.

In this balanced position, which is a volumetric measurement of airflow rate, the control plunger is positioned at a certain point in the fuel distributor, and its horizontal control edge opens the rectangular *metering slits* by a uniform amount. The fuel which flows through these openings is then fed to the fuel injectors.

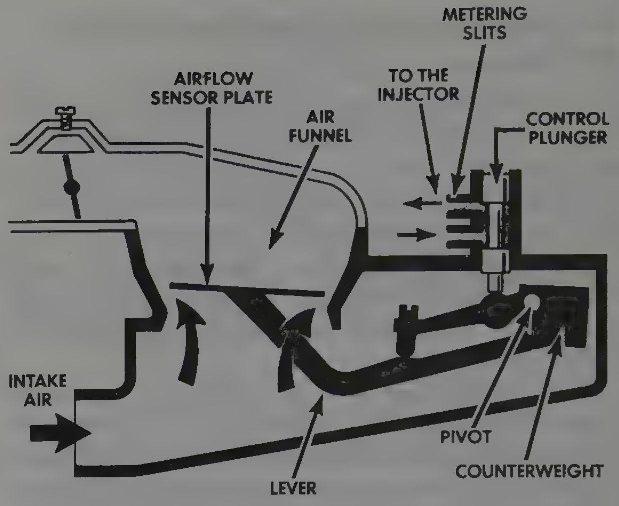


Figure 17-29. The airflow sensor plate is lifted by intake air and moves the control plunger to determine the amount of fuel supplied to the fuel injectors. (Courtesy of Robert Bosch Sales Corporation)

Fuel Distributor. The flow of fuel through a continuous-flow EFI system is shown in Figure 17-30. Fuel is drawn from the *fuel tank* by an *electric fuel pump* into a *fuel damper* and through a *fuel filter*. Filtered fuel enters the *fuel distributor* and flows through a separate line to each *fuel injector*. The *pressure relief valve* limits the pressure to a predetermined value and allows excessive fuel to flow back to the fuel tank through the fuel return line.

The fuel distributor has a separate *pressure regulator valve* (Figure 17-31) for each fuel injector. The pressure regulator valve utilizes a *diaphragm* and *valve spring* to make certain that fuel will be distributed evenly to each cylinder. The *control plunger* of the airflow sensor determines the quantity of fuel flow.

As the airflow sensor plate rises, the control plunger opens the fuel feed to the upper side of the pressure regulator valve diaphragm by way of the *metering ports*. Fuel pressure, plus valve spring pressure on the upper side of the diaphragm, is now greater than the pressure on its lower side. Thus, the diaphragm is pressed downward, causing an increased fuel flow to the fuel injector.

The *warm-up pressure regulator* (Figures 17-30 and 17-32) provides for fuel enrichment during engine warm-up. The parts and operation of the warm-up pressure regulator are shown in Figure 17-32. When the engine is cold, the *bi-*

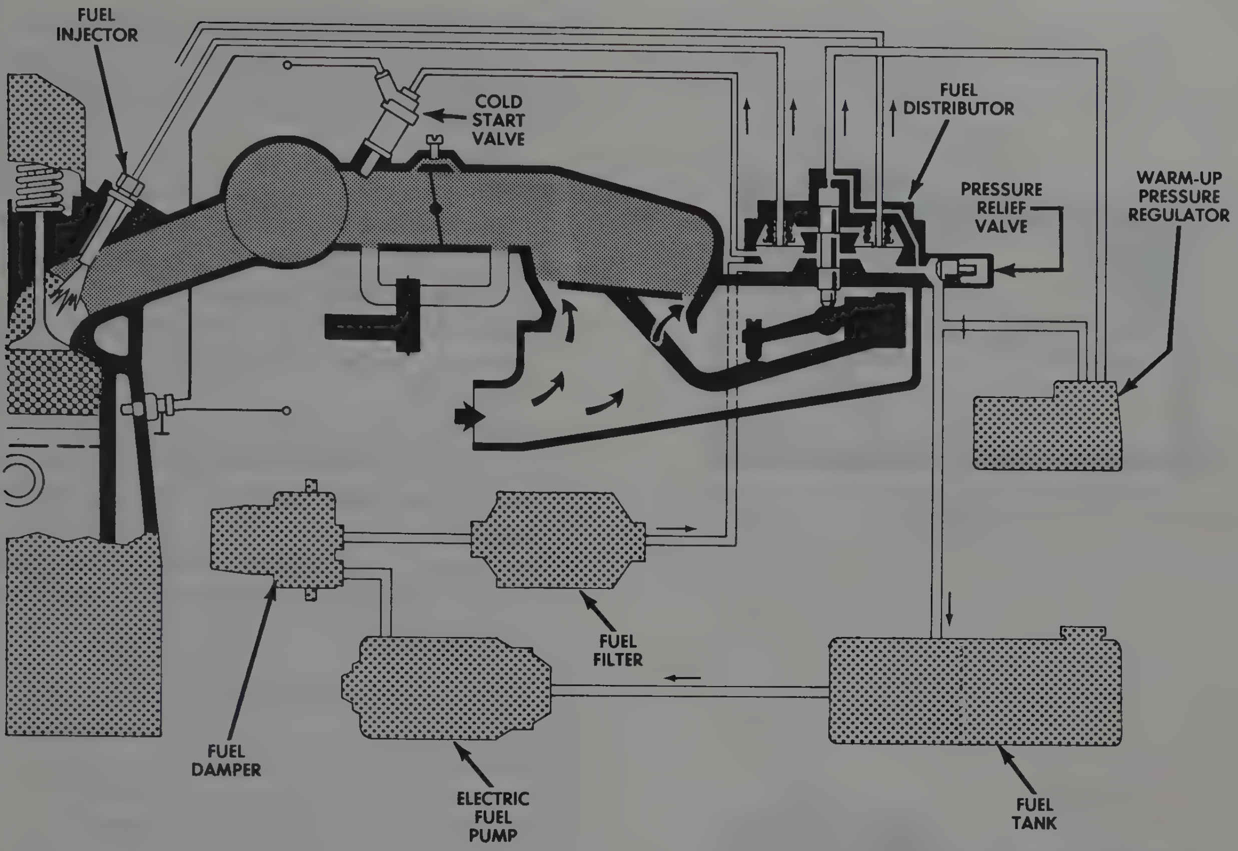

FUEL INJECTOR
COLD START VALVE
FUEL DISTRIBUTOR
PRESSURE RELIEF VALVE
WARM-UP PRESSURE REGULATOR
FUEL FILTER
FUEL DAMPER
ELECTRIC FUEL PUMP
FUEL TANK

Figure 17-30. Fuel flow to the fuel distributor and to the fuel injectors in a continuous-flow EFI system. (Courtesy of Robert Bosch Sales Corporation)

metallic strip presses on the *valve spring.* The *return flow line* is thus opened so that the pressure on the control plunger of the airflow sensor is reduced. This allows the airflow sensor plate to lift the control plunger a little higher, causing more fuel to pass to the fuel injectors, thus enriching the air-fuel mixture. As the bimetallic strip gets warmer, the load is taken off the valve spring and the return flow line is slowly closed. By the time the engine reaches normal operating temperature, the *control pressure* returns to normal, cutting off the enrichment.

Fuel flows to the fuel injectors from the fuel distributor through separate injection lines. The fuel injectors operate automatically at a predetermined pressure and have no metering function.

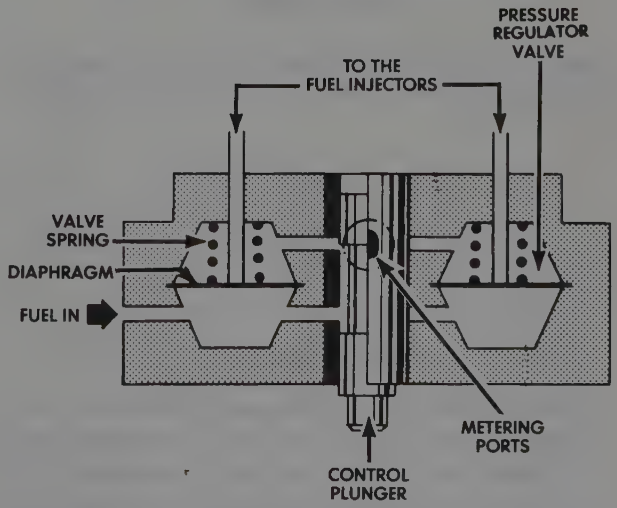
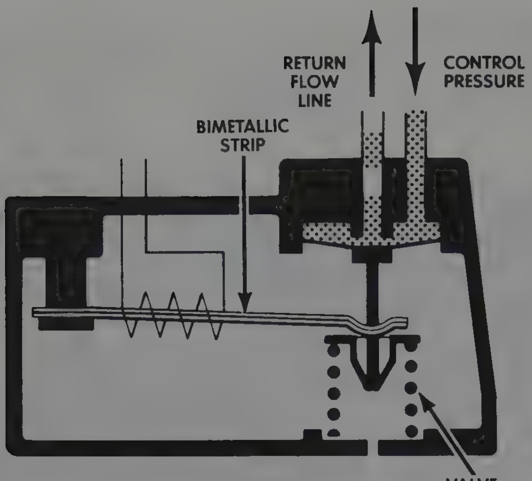
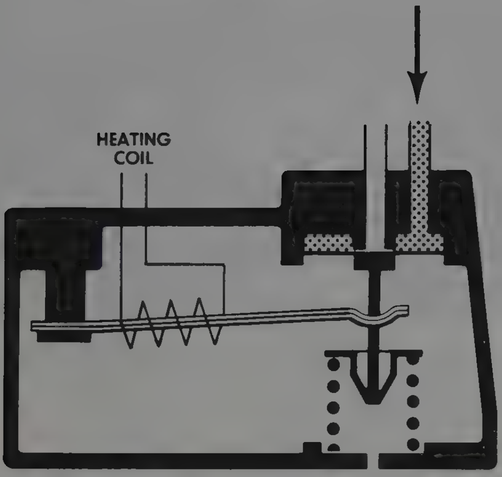

PRESSURE REGULATOR VALVE
TO THE FUEL INJECTORS
VALVE SPRING
DIAPHRAGM
FUEL IN
METERING PORTS
CONTROL PLUNGER

Figure 17-31. The fuel distributor has a separate pressure regulator valve for each fuel injector. (Courtesy of Robert Bosch Sales Corporation)



COLD ENGINE



WARM ENGINE

Figure 17-32. Parts and operation of the warm-up pressure regulator. (Courtesy of Robert Bosch Sales Corporation)

KEY TERMS

Airflow system: An airflow-sensitive timed EFI subsystem. Its purpose is to provide for the flow of air into the engine. The amount of air is measured, and the measurement is used to determine the amount of fuel injected.

Electronic control system: An airflow-sensitive timed EFI subsystem. Its purpose is to sense engine operating conditions and regulate the quantity of fuel injected in relation to airflow.

Fuel flow system: An airflow-sensitive timed EFI subsystem. Its purpose is to provide the correct amount of fuel (gasoline) to each fuel injector.

Fuel injector: A fuel-mixing device that injects the fuel directly into the cylinders or intake manifold.

Lambda probe: A device mounted in the exhaust manifold to monitor the air-fuel ratio. It is often referred to as the oxygen sensor.

Pulse time: The number of milliseconds in which the fuel injectors are open and providing fuel.

SELF-CHECK

1. List the advantages of EFI systems over carburetion systems.
2. Where can fuel be injected into an engine?
3. What is the purpose of the fuel damper?
4. What is the purpose of the fuel injector?
5. What is the purpose of the fuel pressure regulator?
6. What is a cold start valve?
7. Why is the cold start valve connected to a thermo-time switch?
8. How does the airflow meter measure airflow?
9. How can the EFI system have a fast idle system for engine warm-up?
10. What is the purpose of the electronic control system (subsystem)?
11. List the various sensors used in a typical EFI system.
12. What is the purpose of the oxygen sensor?
13. How is pulse time related to engine speed?
14. How does a manifold pressure sensor work?
15. How does the airflow sensor and fuel distributor of a continuous-flow EFI system change fuel injection quantity?

DISCUSSION TOPICS AND ACTIVITIES

1. Use an EFI system on an automobile to identify components and trace air and fuel flow.
2. Build a "bread board" (large board with components hooked up electrically and mechanically) EFI system, using a power source and nonflammable fluid. Operate the system at different speeds and observe the fuel injector outputs.

CERTIFICATION PRACTICE

1. What is the term given to the mixture of air and fuel for complete or full combustion?
   A. Mixture ratio
   B. Stoichiometric air-fuel ratio
   C. Changing ratio
   D. Lambda ratio
2. The airflow meter of the airflow system or subsystem:
   A. Sends a voltage signal to the electronic control unit proportional to the volume of intake air by means of a potentiometer
   B. Controls the volume of intake air
   C. Assumes the function of the throttle valve
   D. Assumes the function of the choke valve
3. The engine requires additional air:
   A. When idling after a cold start
   B. At normal operating temperature
   C. During acceleration
   D. During deceleration
4. In a continuous-flow EFI system, the composition of the air-fuel mixture is determined:
   A. By the airflow sensor
   B. By the fuel distributor
   C. By the interaction of the airflow sensor and the fuel distributor
   D. None of the above
5. Which of the following are types of electronic fuel injection (EFI) systems?
   A. Airflow-sensitive timed
   B. Manifold pressure–sensitive timed
   C. Continuous-flow
   D. All of the above

ANSWERS

1: B, 2: A, 3: A, 4: C, 5: D

Unit 18 TROUBLESHOOTING THE FUEL SYSTEM

A vehicle with a fuel system malfunction may have one or more of the following symptoms (problems):

- The engine will not start or is difficult to start when cold.
- The engine starts but then stalls.
- The engine idles rough and stalls.
- The engine has no power on heavy acceleration or at high speed.
- The engine is difficult to start even after adequate warm-up.
- The engine runs unevenly or surges.
- The engine has poor fuel economy.

Although these are typical fuel system problems, any one of them may also be related to the ignition system or the emissions system. Troubleshooting is essential to determine which system is producing the problem. This unit covers general troubleshooting procedures. However, a service manual should always be consulted for specific, detailed information.

DEVELOPING JOB COMPETENCIES

When you finish reading and studying this unit, you should be able to:

- Measure exhaust CO and HC content.
- Troubleshoot a carburetion system.
- Troubleshoot an electronic fuel injection (EFI) system.

CHECKING AIR-FUEL MIXTURE

A fuel system problem results when the engine is not supplied with fuel or when it is supplied with an air-fuel mixture that is too rich or too lean. One of the first steps in troubleshooting the fuel system is to check the air-fuel mixture.

Visual Check of Air-Fuel Mixture

If an exhaust analyzer is not available, a quick check of the air-fuel mixture may be made by examining the condition of the spark plugs. The vehicle should be test-driven and then the engine turned off without allowing it to idle for a long period of time. The spark plugs should be removed and compared to a *spark plug analysis chart* as explained in Unit 14. A dry spark plug (Figure 18-1) indicates that the air-fuel mixture is too lean. A wet spark plug (Figure 18-2) indicates that the mixture is too rich.

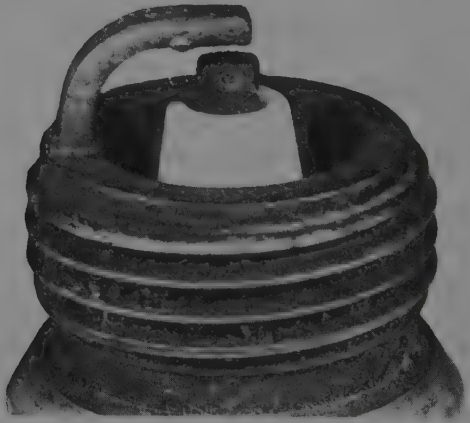


Figure 18-1. A dry spark plug indicates a lean air-fuel mixture.

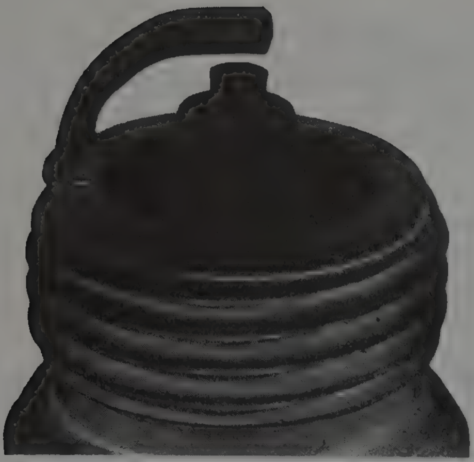


Figure 18-2. A wet spark plug indicates a rich air-fuel mixture.

Using an Exhaust Analyzer to Check Air-Fuel Mixture

The most accurate way to determine if the air-fuel mixture is correct is to use an infrared exhaust analyzer. It measures the amount of carbon monoxide (CO) and unburned hydrocarbons (HC) in the exhaust.

The CO reading is given as a percent (%). The higher the percentage of CO, the richer the air-fuel mixture is. (The CO specifications for a vehicle may be given on an under-the-hood label or in the appropriate service manual.)

The HC reading measures unburned hydrocarbons in the exhaust. This reading shows how much gasoline does not get burned in the cylinders. The readings are in *parts per million* (PPM). High HC levels are caused by leaking exhaust valves, ignition misfires, or intake manifold leaks that can make the air-fuel mixture too lean to ignite.

The operator's manual for the infrared exhaust analyzer normally provides a test procedure for the tune-up technician to follow and a diagnostic chart (Figure 18-3) to help interpret the results. It is useful for testing much more than just the fuel system. Anything that affects combustion, such as ignition, compression, and emission systems, can be observed with the help of the infrared exhaust analyzer.

After the exhaust analyzer is connected to the vehicle and calibrated, a series of tests determine whether carbon monoxide (CO) and hydrocarbon (HC) levels are within specifications. Tests are normally conducted at idle speed, cruising speed, and during acceleration and deceleration. The tester (analyzer) is often used with a chassis dynamometer so that actual road conditions can be simulated.

Low CO readings and high HC readings during cruising operation, with surging, indicate an air-fuel mixture that is too lean. **Surging** occurs when engine speed increases and decreases with the same throttle setting. Normal CO readings and high HC readings during cruising operation, with black smoke, indicate (1) incorrect float setting, (2) a cruise circuit that is too rich, or (3) incorrect power circuit action.

High CO and HC readings at idle, with rough idling and black smoke, indicate (1) incorrect float setting, (2) poor choke action, (3) an idle mixture that is too rich, (4) leaking needle valve and seat, or (5) leaking power valve.

CARBURETION SYSTEM TROUBLESHOOTING

When troubleshooting a carburetion system, find a *carburetor troubleshooting chart* in the service manual for that particular vehicle and model of carburetor. The chart will provide a step-by-step procedure to find the problem. Typical carburetor troubleshooting charts are shown in Figures 18-4 and 18-5 — one for a *no-start condition* and the other for *poor fuel economy*. Some general troubleshooting procedures appropriate for most carburetion systems follow.

Cold Starting Problems

When a cold engine cranks but will not start, and no electrical problems exist, the cause may be one of the following:

- Improper starting procedure used.
- No fuel in the fuel tank.
- Choke valve not closing far enough when cold. (see Unit 16, under the heading of "Choke System," for detailed discussion).
- Choke valve or linkage binding or sticking.
- No fuel in the carburetor.
- Engine flooded.

Check the vehicle's operating manual to make sure the proper starting procedure is used. Make sure there is fuel in the tank. Add 1 or 2 gallons of gasoline, and check the fuel gage for proper operation.

EXHAUST DIAGNOSTIC CHART

		Approx. Speed				
		Idle	1000 RPM	2000 RPM	Test Results	Typical Malfunctions
1	CO				Normal	Poor point action Defective Electronic Ignition Open plug wire or fouled plug.
	HC	Hi	Hi	Hi	High all speeds	
2	CO				Normal	Vacuum leak affecting one cylinder.
	HC	Hi	Hi	Hi	Unsteady	
3	CO	Lo	Lo	Lo	Low	General vacuum leak.
	HC	Hi	Hi		Hi at low RPM	Should decrease at higher RPM.
4	CO	Hi			Hi at idle	PCV valve restricted or carburetor idle mixture misadjusted.
	HC				Above normal	
5	CO	Hi	Hi	Hi	Hi at all RPM	Dirty air cleaner choke malfunction or carburetor malfunction.
	HC				Above normal	
6	CO	Hi	Hi		Hi low speeds	Rich carburetor adjustment.
	HC	Hi			Hi at idle	
7	CO				Normal	Ignition misfire at high speed or floating exhaust valves.
	HC			Hi	Hi at high RPM	
8	CO				Normal	Compression loss or vacuum leak.
	HC	Hi			Hi at idle only	
9	CO	Lo			Very Lo at idle only	Lean carburetor adjustment.
	HC	Hi			Hi at idle only	

Figure 18-3. Typical diagnostic chart in an operator's manual for an infrared exhaust analyzer. (Courtesy of Marquette Products, Automotive Division of Applied Power, Inc.)

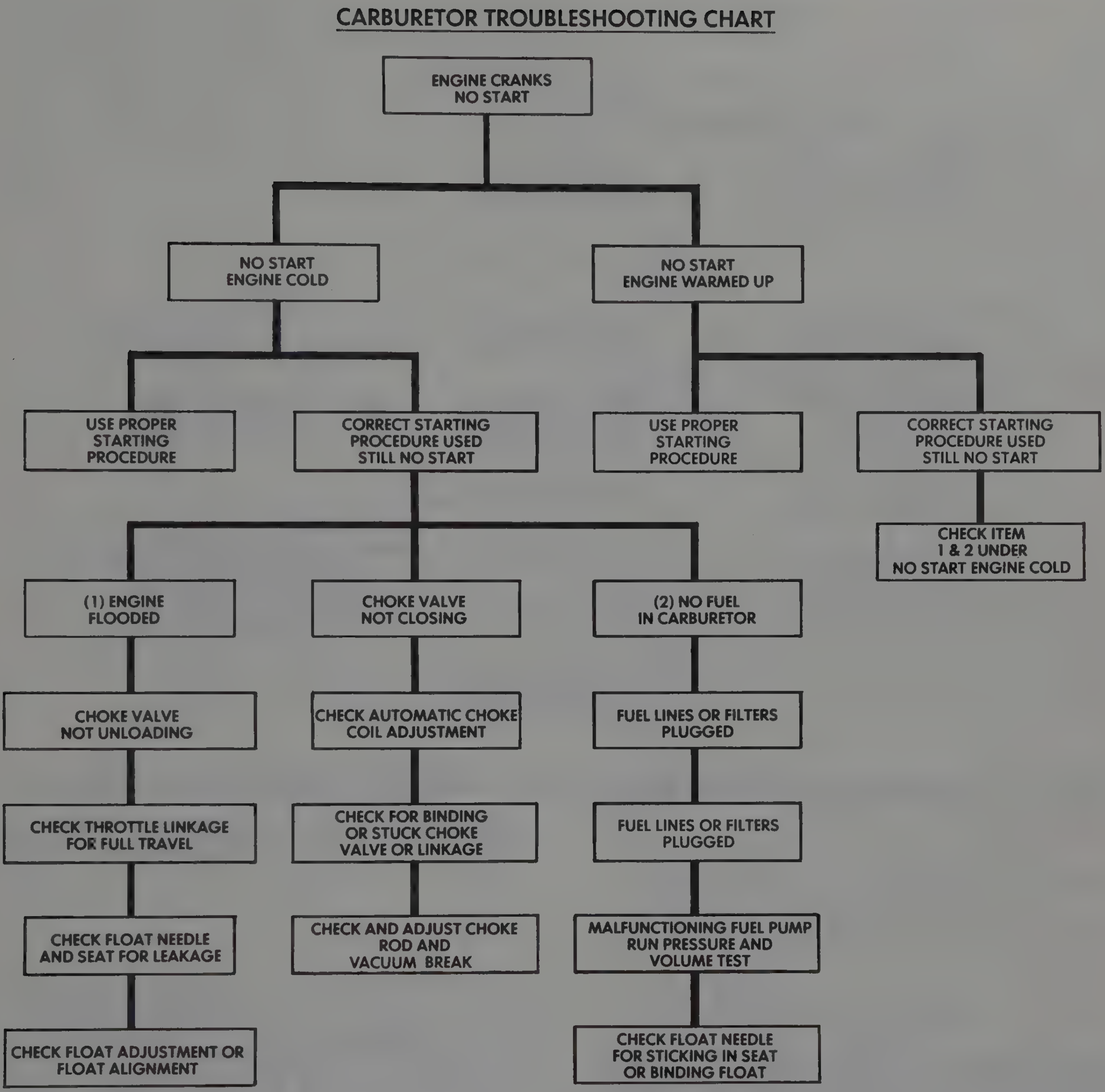

CARBURETOR TROUBLESHOOTING CHART
ENGINE CRANKS NO START
NO START ENGINE COLD
NO START ENGINE WARMED UP
USE PROPER STARTING PROCEDURE
CORRECT STARTING PROCEDURE USED STILL NO START
USE PROPER STARTING PROCEDURE
CORRECT STARTING PROCEDURE USED STILL NO START
CHECK ITEM 1 & 2 UNDER NO START ENGINE COLD
(1) ENGINE FLOODED
CHOKE VALVE NOT CLOSING
(2) NO FUEL IN CARBURETOR
CHOKE VALVE NOT UNLOADING
CHECK AUTOMATIC CHOKE COIL ADJUSTMENT
FUEL LINES OR FILTERS PLUGGED
CHECK THROTTLE LINKAGE FOR FULL TRAVEL
CHECK FOR BINDING OR STUCK CHOKE VALVE OR LINKAGE
FUEL LINES OR FILTERS PLUGGED
CHECK FLOAT NEEDLE AND SEAT FOR LEAKAGE
CHECK AND ADJUST CHOKE ROD AND VACUUM BREAK
MALFUNCTIONING FUEL PUMP RUN PRESSURE AND VOLUME TEST
CHECK FLOAT ADJUSTMENT OR FLOAT ALIGNMENT
CHECK FLOAT NEEDLE FOR STICKING IN SEAT OR BINDING FLOAT

Figure 18-4. Typical carburetor troubleshooting chart for a no-start condition. (Courtesy of Cadillac Motor Car Division, General Motors Corporation)

Remove the air cleaner, and check the choke action. Adjust the choke setting, or realign the choke valve or linkage as necessary. If the choke valve is clogged by dirt and gum (a sticky deposit), clean with appropriate choke cleaner.

CAUTION: Do not oil the choke linkage.

Check for fuel to the carburetor by pumping the accelerator linkage. There should be a visible discharge of fuel into the carburetor

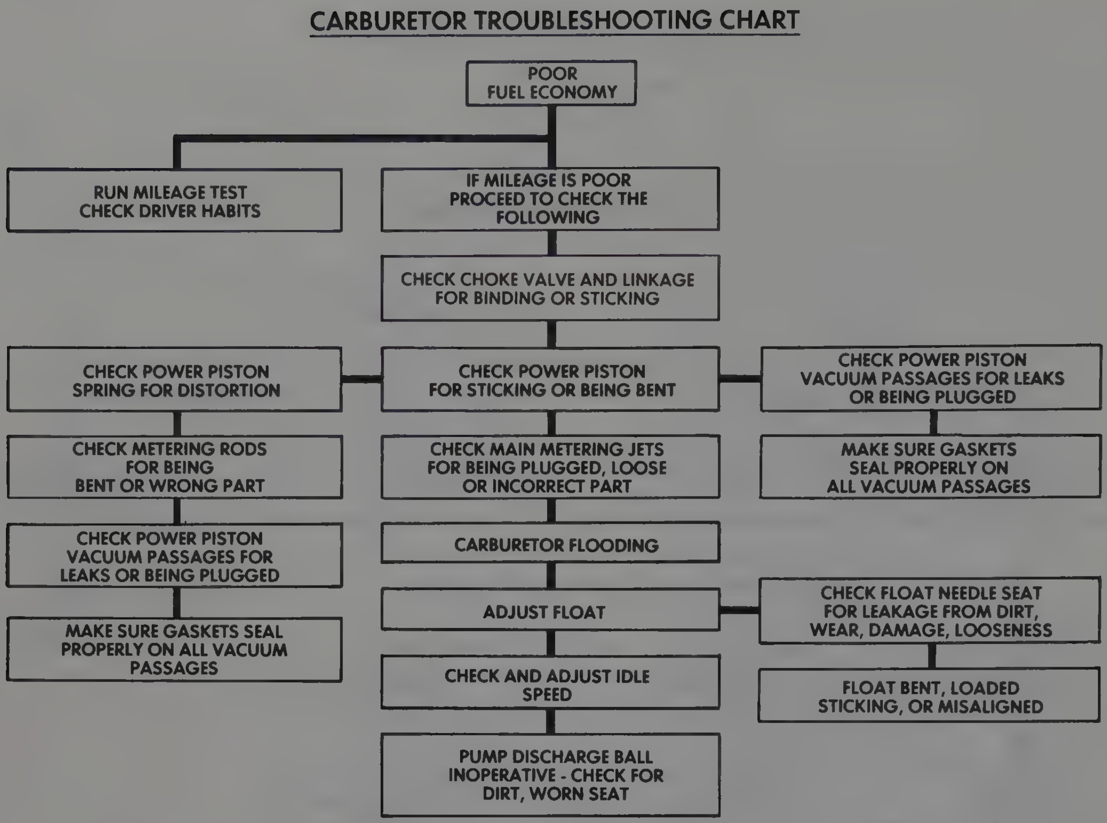

CARBURETOR TROUBLESHOOTING CHART
POOR FUEL ECONOMY
RUN MILEAGE TEST CHECK DRIVER HABITS
IF MILEAGE IS POOR PROCEED TO CHECK THE FOLLOWING
CHECK CHOKE VALVE AND LINKAGE FOR BINDING OR STICKING
CHECK POWER PISTON SPRING FOR DISTORTION
CHECK POWER PISTON FOR STICKING OR BEING BENT
CHECK POWER PISTON VACUUM PASSAGES FOR LEAKS OR BEING PLUGGED
CHECK METERING RODS FOR BEING BENT OR WRONG PART
CHECK MAIN METERING JETS FOR BEING PLUGGED, LOOSE OR INCORRECT PART
MAKE SURE GASKETS SEAL PROPERLY ON ALL VACUUM PASSAGES
CHECK POWER PISTON VACUUM PASSAGES FOR LEAKS OR BEING PLUGGED
CARBURETOR FLOODING
MAKE SURE GASKETS SEAL PROPERLY ON ALL VACUUM PASSAGES
ADJUST FLOAT
CHECK FLOAT NEEDLE SEAT FOR LEAKAGE FROM DIRT, WEAR, DAMAGE, LOOSENESS
CHECK AND ADJUST IDLE SPEED
FLOAT BENT, LOADED STICKING, OR MISALIGNED
PUMP DISCHARGE BALL INOPERATIVE - CHECK FOR DIRT, WORN SEAT

Figure 18-5. Typical carburetor troubleshooting chart for poor fuel economy. (Courtesy of Cadillac Motor Car Division, General Motors Corporation)

barrel (Figure 18-6). If not, remove the fuel line at the carburetor, and connect a hose to the fuel line to allow fuel to run into a metal container. Remove the high-voltage cable (or stinger) from the center tower of the distributor cap, and ground the stinger. Crank the engine. If there is no fuel discharge from the fuel line, check for kinked or bent fuel lines. Disconnect the fuel line at the tank, and blow it out with an air hose.

WARNING: Be sure to wear eye protection and a respirator when blowing out a fuel line with compressed air. (See Unit 2, under the heading of "Using Compressed Air.")

Reconnect the line and check again for fuel discharge. If there is still no discharge, replace the fuel pump.

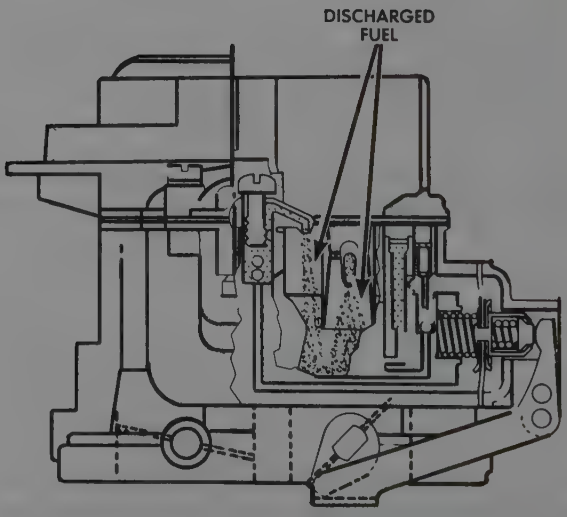
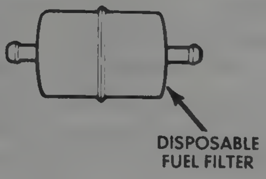
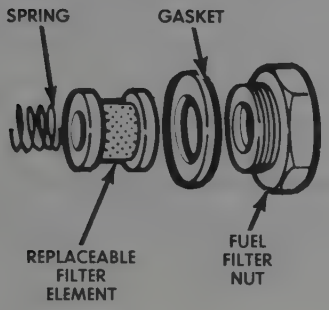

DISCHARGED FUEL

Figure 18-6. Fuel should be seen discharging into the carburetor barrel when the accelerator linkage is pumped. (Courtesy of Chevrolet Motor Division, General Motors Corporation)

If the fuel supply is correct, inspect the fuel filters. If they are plugged, replace the *fuel filter* or *filter element*, depending on the type used (Figure 18-7). If the filters are in good condition, check the float system (covered in Unit 16) for a bind in the float mechanism or a sticking needle valve.



IN-LINE DISPOSABLE TYPE



IN-LINE CARBURETOR-MOUNTED TYPE

Figure 18-7. A plugged fuel filter prevents fuel flow into the carburetor. (Courtesy of Chevrolet Motor Division, General Motors Corporation)

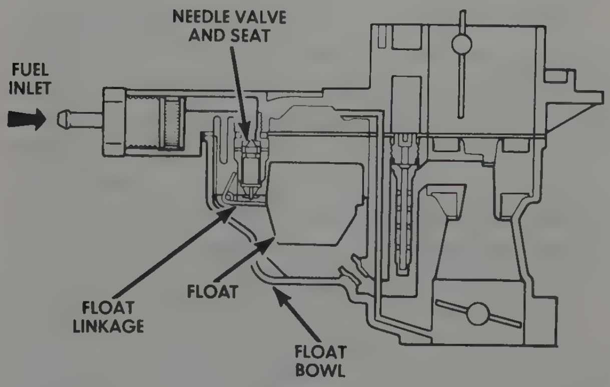


Figure 18-8. The needle valve and seat must seal, or the fuel level will rise in the float bowl and cause flooding. (Courtesy of Chrysler Corporation)

To check for flooding, remove the air cleaner (with the engine turned off), and look into the carburetor barrel(s). If the carburetor is flooded, fuel will be dripping from the main nozzles and/or the carburetor will be very wet with fuel.

A common cause of flooding in the fuel system is dirt between the *needle valve and seat*, preventing fuel shut-off to the *float bowl* (Figure 18-8). If there is dirt in the fuel system, the carburetor will have to be removed, disassembled, and cleaned.

Check the needle valve and seat for proper seal by very carefully (avoid breathing in fumes) applying mouth suction to draw the needle valve against the seat. The needle valve should stop airflow in the closed position. If the needle valve is defective, replace it with a new needle valve and seat. Be sure to replace fuel filters. Check a *hollow-type float* to make sure it is filled with fuel, and check for any damage to the *float linkage*. A *solid-type float* can be checked for fuel absorption by lightly squeezing it between your fingers. If wetness (fuel) appears on its surface, or if the float feels heavy (as compared to the weight of a good float), replace the float.

Engine Stalling Problems

When the engine starts but then stalls, the problem may be one of the following:

- Engine's idle speed is too slow when cold.
- Choke coil rod is out of adjustment.
- Choke valve and/or linkage is sticking or binding.
- Incorrect idle speed setting.
- Not enough fuel in carburetor.
- Carburetor is flooding.

Check and reset the fast idle setting and the fast idle cam. Move the choke valve by hand, inspecting for smooth operation. Clean and/or adjust the choke linkage and choke coil rod as required. Use a tachometer to make sure the engine idle speed is set to specifications. Check the fuel filter for plugging. If the carburetor is flooding, check the needle valve and seat as described earlier under the heading of "Cold Starting Problems."

Fuel Pump Pressure and Volume. The fuel pump may be working, but not providing enough pressure or volume. **Fuel pump pressure** is a measurement of fuel pump output (pressure) taken with a pressure gage. **Fuel pump volume** is the quantity delivered in a specific time period.

To test the fuel pump pressure (Figure 18-9), first remove the air cleaner from the *carburetor*. **WARNING: Use care to prevent a fire from fuel spillage.** Disconnect the fuel *inlet line* or fuel filter at the carburetor. Disconnect the fuel return line at the fuel filter (if equipped), and plug the end of the filter. Connect the *pressure gage*, *hose restrictor*, and *flexible hose* between the fuel *inlet line* and *carburetor* (Figure 18-9).

Position the flexible hose and hose restrictor so that fuel can be discharged into a suitable *graduated container*. Before taking a pressure reading, operate the engine at *curb idle speed* (see Unit 19, under the heading of "Idle Speed Adjustments"), and vent the system into the container by momentarily opening the hose restrictor. Close the hose restrictor, allow pressure to stabilize, and note the pressure gage reading. Compare the pressure reading to specifications. If the reading is above or below specifications, replace the fuel pump.

If the pump pressure is within specifications, perform the fuel pump volume test. Operate the engine at curb idle speed. Open the hose restrictor, and allow fuel to discharge into a graduated container for 30 seconds, then close the hose restrictor. Compare the volume in the graduated container to specifications. If the fuel pump has not delivered enough volume, replace it.

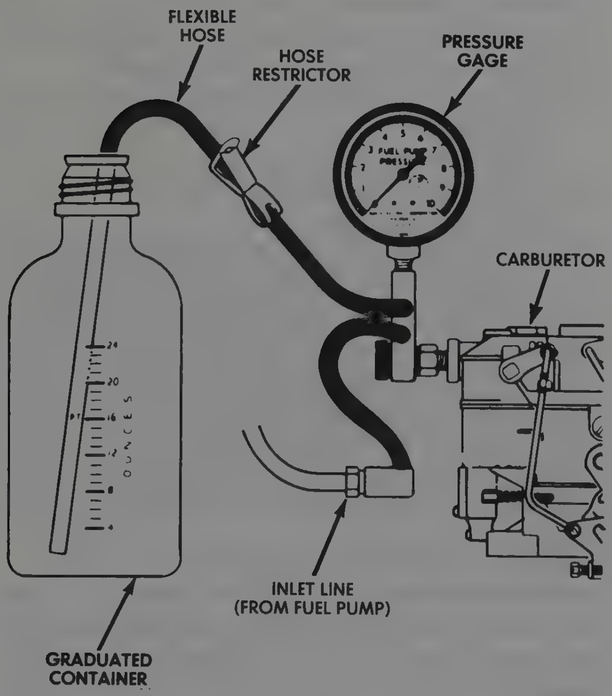


Figure 18-9. The fuel pump is tested for pressure and volume. (Courtesy of American Motors Corporation)

Rough Idle and Stalling Problems

An engine that idles rough and stalls may have one or more of the following problems:

- Incorrect idle speed setting.
- Disconnected or improperly installed manifold vacuum hoses.
- A carburetor that is loose on the intake manifold.
- Loose intake manifold or defective gaskets.
- A carburetor that is flooding.

Reset idle speed following the instructions and specifications given on a decal in the engine compartment, or check the service manual. Check all vacuum hoses leading into the manifold or carburetor base for leaks or for being disconnected, and replace them as necessary. Check the torque on the carburetor to the manifold mounting bolts. Using a pressurized oil can, spray light oil around the manifold legs and carburetor base. If engine RPM changes, tighten or replace the manifold gaskets or carburetor base gasket as necessary. If flooding is the problem, perform the procedures described earlier under the heading of "Cold Starting Problems."

Acceleration and High-speed Problems

If the engine hesitates on acceleration or does not have enough power at high speed, it may have one or more of the following problems:

- Defective acceleration system (see Unit 16 for detailed information on the acceleration system).
- Incorrect fuel level in float bowl.
- Throttle valve not opening all the way.
- Dirty or plugged fuel filter.
- Defective power system (see Unit 16 for detailed information on the power system).
- Dirty or plugged main metering jets.

A quick check of the acceleration system can be made with the engine turned off. Remove the air cleaner. Look into the carburetor barrel(s) to observe the stream of fuel while quickly opening the throttle valve. A stream of fuel should be observed striking near the center of the venturi area. If there is fuel in the carburetor but no stream of fuel is observed, the acceleration system must be disassembled and serviced.

Check for a sticking needle valve or binding float in the float system (covered in Unit 16). Free the sticking parts or replace them as necessary. Check and reset the float level to specifications. Check and adjust throttle linkage to obtain a wide-open throttle in the carburetor.

Check the power system for a power valve or power piston that is stuck or binding. If a power piston is sticking, check it and its cavity for dirt or scores. Also, check the piston spring for distortion. Clean or replace the power valve as necessary. If the main metering jets (part of the main metering system, covered in Unit 16) are plugged or dirty and excessive dirt is in the float bowl, the carburetor should be completely disassembled and cleaned.

Engine Starting Problems with Adequately Warmed Engine

If the engine is difficult to start after initial warm-up, check for the following problems:

- Choke valve not opening completely (see Unit 16, under the heading of "Choke System," for detailed information).
- Carburetor is flooding.
- No fuel in carburetor.
- Leaking float bowl (see Unit 16, under the heading of "Float System," for detailed information).
- Fuel restriction.
- Dirt or water in fuel system.
- Incorrect fuel level in float bowl.
- Power system in carburetor not functioning properly (covered in Unit 16).
- Power valve or power piston sticking in the down position.
- Vacuum leakage.

Remove the air cleaner and check for proper choke valve opening. Check the carburetor for signs of flooding. Pump the accelerator linkage and check for proper fuel delivery. Check the carburetor carefully for fuel or vacuum leakage.

If the carburetor needs disassembly, carefully inspect the condition of the power valve and replace it if necessary.

Poor Fuel Economy

Poor fuel economy may be due to one of the following problems:

- Engine needs complete tune-up.
- Choke valve not fully opening (see Unit 16, under the heading of "Choke System," for detailed information).
- Fuel leaks.
- Power system in carburetor not functioning properly (see Unit 16 for detailed information).
- High fuel level in carburetor, or carburetor is flooding.
- Dirty or plugged air bleeds or fuel passages in carburetor.

Before checking carburetor parts, the tune-up technician should ask the owner when the vehicle had its last tune-up and check this information against the recommended tune-up interval.

Check the air filter element to see if it is excessively dirty and replace if necessary. Check the float level, choke valve, and power valve as described earlier in this unit. A dirty carburetor with plugged air or fuel passages must be removed, disassembled, and cleaned.

FUEL INJECTION SYSTEM (EFI) TROUBLESHOOTING

Fuel injection problems cause the same general symptoms as those described for carburetion systems.

NOTE: Troubleshooting an electronic fuel injection (EFI) system should not be attempted without a detailed troubleshooting procedure provided in the manufacturer's service manual.

A typical troubleshooting guide for a fuel injection system is shown in Figure 18-10.

There are three basic fuel injection testing methods. One uses a manufacturer-supplied tester, which is designed for a specific type of EFI system. Another method uses an oscilloscope. Many oscilloscopes have a function switch to allow viewing of fuel injector pulse voltages. This is used along with a power balance test (covered in Unit 7). A third method uses a voltmeter and ohmmeter along with a pressure gage to make basic system checks. Since this is the most common method, it is the one described in this unit.

General Safety Precautions for Servicing an EFI System

When checking or servicing an EFI system, observe these safety precautions:

1. The fuel system is under high pressure. Always wear eye protection to avoid fuel being squirted in the eyes.

2. The high pressure in the fuel lines makes opening a fuel line dangerous. Also,

TROUBLESHOOTING GUIDE

SYMPTOM										
Engine cranks but does not start	Engine starts but then dies	Rough or unstable idle	Idle speed incorrect	CO value incorrect	Erratic running	Engine misses when driving	Fuel consumption too high	No maximum power	**CAUSE**	**REMEDY**
●	●	●	●		●	●	●	●	Defect in ignition system	Check battery, distributor, plugs, coil and timing
●	●	●	●		●	●	●	●	Mechanical defect in engine	Check compression, valve adj. and oil pressure
●	●	●	●	●	●	●		●	Leaks in air intake system (false air)	Check all hoses and connections, eliminate leaks
●	●	●						●	Blockage in fuel system	Check fuel tank, filter and lines for free flow
●									Relay defective: wire to injector open	Test relay, check wiring harness
●									Fuel pump not operating	Check pump fuse, pump relay and pump
●	●	●		●	●		●	●	Fuel system pressure incorrect	Check pressure regulator
●									Cold start valve not operating	Test for spray, check wiring and thermo-time switch
●	●	●	●	●	●		●		Cold start valve leaking	Check valve for leakage
●									Thermo-time switch defective	Test for resistance readings vs. temperature
●	●	●	●						Auxiliary air valve not operating correctly	Must be open with cold engine: closed with warm
●	●	●		●			●		Temperature sensor defective	Test for 2-3 kΩ at 68°F
●	●	●	●	●	●		●	●	Air flow meter defective	Check pump contacts, test flap for free movement
		●	●					●	Throttle butterfly does not completely close or open	Readjust throttle stops
		●						●	Throttle valve switch defective	Check with ohmmeter and adjust
	●	●	●	●					Idle speed incorrectly adjusted	Adjust idle speed with bypass screw
		●		●	●	●		●	Defective injection valve	Check valves individually for spray
	●	●	●	●	●		●		CO concentration incorrectly set	Readjust CO with screw on air flow meter
●	●	●			●	●			Loose connection in wiring harness or system ground	Check and clean all connections
●	●	●				●		●	Control unit defective	Use known good unit to confirm defect

Figure 18-10. Typical troubleshooting guide for an electronic fuel injection (EFI) system. (Courtesy of Robert Bosch Sales Corporation)

a loose connection can deliver a great deal of atomized, highly pressurized fuel. Be extremely careful to avoid a fire or personal injury.

3. Never start an engine when the battery connections are loose, or the electronic control unit may be damaged.

4. Never start an engine when a fast charge is being applied to the battery, or the electronic control unit may be damaged.

5. Always disconnect battery teminals from the battery when using a booster-charger to charge the battery.

6. Never detach or attach a wiring harness or terminal plug to or from the electronic control unit when the ignition switch is on.

7. Never start any diagnosis or repair of the EFI system until the ignition system has been completely checked (points, spark plugs, dwell, timing, spark plug wire, and so forth).

8. Never start any diagnosis or repair of the EFI system until the circuits from the main wiring harness going into the dual relay have been completely checked.

9. Whenever using an ohmmeter, make sure the ignition switch is in the OFF position. Ohmmeters can be damaged if subjected to a live circuit.

10. Do not operate the fuel pump when there is no fuel in the lines.

11. Do not reuse fuel hose clamps and always torque them to specifications.

EFI System Quick Checks

Problems in an EFI system often occur in the connections between the components. Therefore, a quick check of all harnesses and connectors (Figure 18-11) should be performed for looseness or corrosion. All the harnesses and connectors should be disconnected and inspected, then reconnected.

Since an EFI system accurately meters the intake airflow through an airflow meter, even a slight air leak causes an improper air-fuel mixture, resulting in faulty engine operation. For this reason, a thorough inspection for air leaks should be made at the oil filler cap, dipstick, blow-by hoses (See Unit 20, under the heading of "Controlling Crankcase Emissions") and at the airflow meter to the throttle chamber connection.

A no-start condition is often caused by a malfunction of the electric fuel pump. If the electric fuel pump does not buzz for a second or two when the ignition is turned on, check the pump fuse. All EFI electric fuel pumps are fused someplace in the vehicle's electrical circuit.

Often an electric fuel pump is so worn that it draws too much current and blows its protective fuse. This action is similar to a "dragging" starter that draws too much cranking amperage. In colder weather, moisture in the fuel can cause an electric fuel pump to freeze. The frozen pump will also draw too much current and blow the pump fuse.

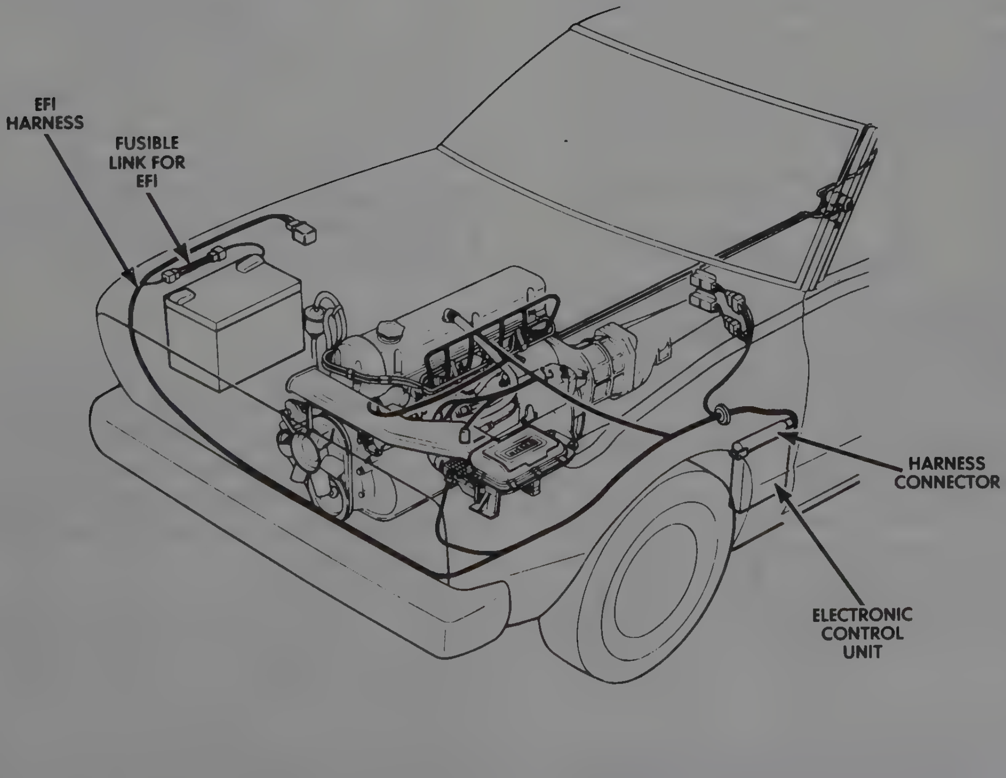


Figure 18-11. Typical locations of the EFI harnesses and connectors. (Courtesy of Nissan Motor Corporation in U.S.A.)

Another common problem is worn fuel hoses (lines). Replace fuel hoses if they are deformed, scratched, or chafed.

WARNING: Do not reuse fuel hose clamps after removal. Always replace them. The typical locations of fuel hose connections are shown in Figure 18-12.

A plugged or inoperative fuel injector is a common cause of poor idle, low power, and engine misfire. It can be revealed by several methods. One method is a power balance test. If the ignition system is operating correctly, and there is little or no RPM drop when a cylinder is "shorted," the problem could be a vacuum leak at the fuel injector seal. O-rings are a potential source of vacuum leak on any EFI system.

If O-rings are sealing properly, then a faulty fuel injector is probably responsible for the problem. By placing your finger on a good (functioning properly) fuel injector, you can feel it clicking open and closed. By placing a stethoscope on a good injector, you can hear it clicking open and closed. If not, a poor electrical connection may exist at that fuel injector. Switch the fuel injector wires with an adjacent, good fuel injector. If switching the wires causes it to work, the problem is electrical. Check the circuit for a corroded or loose connection. Make sure you check the cold start valve on a vehicle with a cold or hot starting problem. It may be plugged or stuck open.

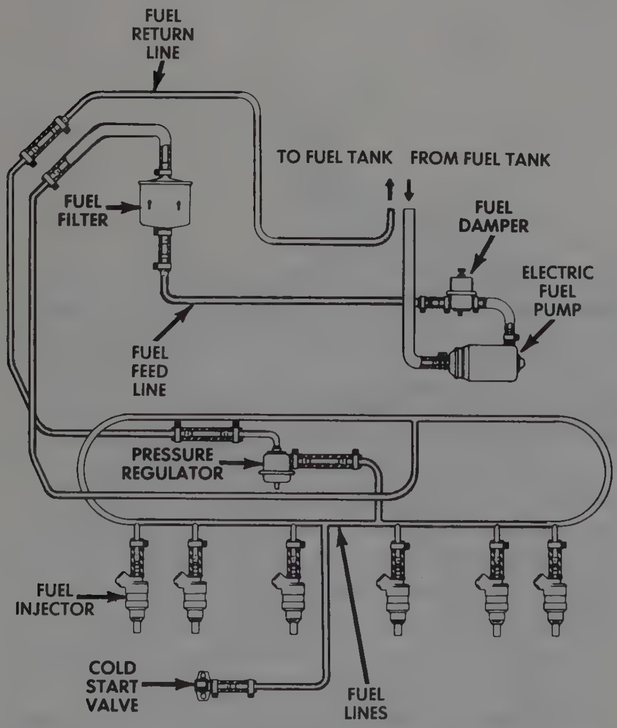


Figure 18-12. Typical locations of fuel hoses (or lines) that must be checked for leaks. (Courtesy of Nissan Motor Corporation in U.S.A.)

Pressure Testing

The fuel pressure on an EFI system is checked with a *pressure gage* installed in the *fuel line* at a point where the fuel has passed through the *fuel filter* (Figure 18-13). For pressure testing the EFI system, an accurate pressure gage is needed that reads from zero to 50 PSI in 0.5 PSI increments. High operating pressures make tight connections very important. These pressures will not tolerate haphazard connections.

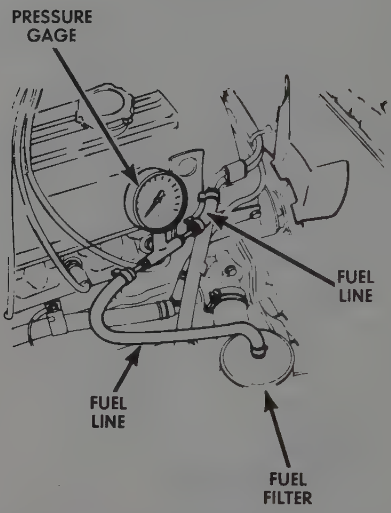


Figure 18-13. EFI fuel pressures are measured with a pressure gage installed in the fuel line at a point where the fuel has passed through the fuel filter. (Courtesy of Nissan Motor Corporation in U.S.A.)

WARNING: To avoid a fire when connecting the gage, use a reinforced fuel line hose that will withstand high pressures, and use worm-gear clamps to secure it. Look for leakage in the fuel lines on every EFI system you test.

Take a pressure reading at the idle engine speed recommended by the manufacturer and compare the reading to specifications. When the fuel pressure reading is taken at idle, normal fuel injector pulsation will cause the gage to fluctuate. This pulsation is most pronounced on four-cylinder engines. Watch the pressure gage needle carefully, and record the average pressure value. At idle, take the midpoint between the highest and lowest fluctuations (pulsations) of the pressure gage needle as the pressure reading.

If fuel pressure is not within specifications at idle, the problem may be a clogged fuel filter, a restricted fuel line, or a restricted fuel return line. After taking the idle fuel pressure reading, shut off the engine and watch the pressure gage. It should hold at 17-20 PSI. If the pressure drops to zero, there is a leak in the EFI system.

Voltage and Resistance Checks

The operation of the electronic control unit can be checked by substituting another electronic control unit. If the EFI system problem disappears, the old electronic control unit can be considered defective. Each of the other electronic components can be checked for continuity, voltage, and resistance with an appropriate meter.

Many of the electrical components can be checked through the large electrical connector that plugs into the electronic control unit. **CAUTION. Before disconnecting the electrical connector, make sure that the ignition switch is in the OFF position.**

Typical connections for measuring voltage and resistance at the electrical connector are shown in Figures 18-14 and 18-15, respectively. Consult the service manual for the resistance and voltage values at each connection. The manual will also indicate which component to replace if the values are not correct.

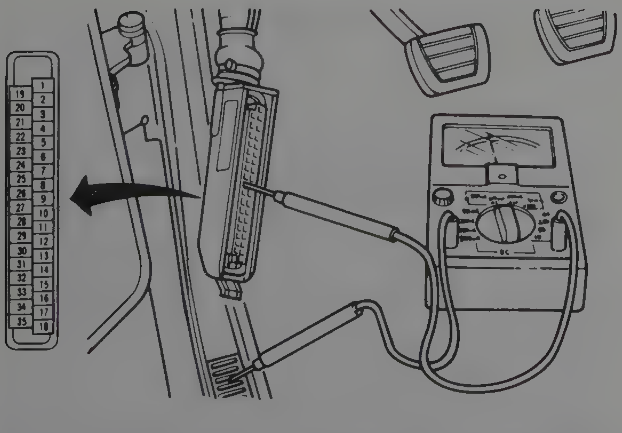


Figure 18-14. Typical connections for a voltage check at the EFI electrical connector. (Courtesy of Nissan Motor Corporation in U.S.A.)

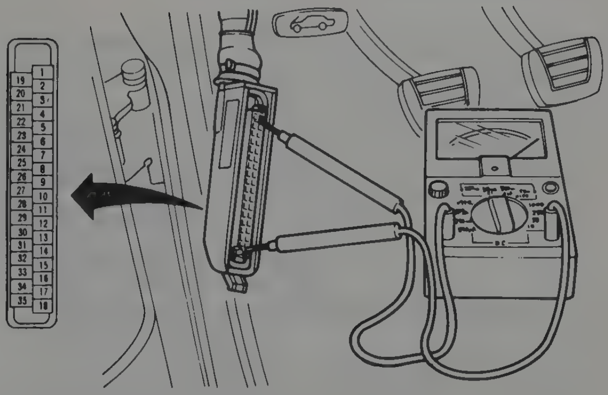


Figure 18-15. Typical connections for a resistance check at the EFI electrical connector. (Courtesy of Nissan Motor Corporation in U.S.A.)

KEY TERMS

Fuel pump pressure: A measurement of fuel pump output taken with a pressure gage and compared to specifications.

Fuel pump volume: The quantity of fuel a fuel pump can deliver in a specific time period.

Surging: An engine performance problem in which engine speed increases and decreases with the same throttle setting.

SELF-CHECK

1. List five vehicle malfunctions that can be caused by a problem with the fuel system.
2. What other engine systems can cause problems similar to those produced by a malfunctioning fuel system?
3. What are two ways of checking whether an engine is receiving the correct air-fuel mixture?
4. What do low CO readings and high HC readings along with surging indicate?
5. What can cause a cold starting problem?
6. What can cause an engine stalling problem?
7. What type of equipment is used to troubleshoot an EFI system?
8. Why should eye protection be worn when servicing an EFI system?

9. Why is the possibility of a fire greater when servicing an EFI system than when servicing a carburetion system?
10. How can the existence of a problem in an EFI electronic control unit be determined?

DISCUSSION TOPICS AND ACTIVITIES

1. Connect an infrared exhaust analyzer to a shop engine. “Bug” (create typical problems in) the various carburetor circuits and observe the HC and CO readings.
2. Perform a complete pressure check and electrical check on an EFI system using a manufacturer’s shop manual.

CERTIFICATION PRACTICE

1. High CO and HC readings taken at idle on a carburetion system could be caused by:
   A. Incorrect float setting
   B. Poor choke action
   C. Leaky needle valve and seat
   D. All of the above
2. In an engine with a carburetion system, a stalling problem may be due to:
   A. Carburetor flooding
   B. Incorrect idle speed setting
   C. Incorrect choke adjustment
   D. All of the above
3. A fuel pump is tested for:
   A. Volume
   B. Pressure
   C. Both A and B
   D. Neither A nor B
4. When an engine with an EFI system is turned off:
   A. There is pressure in the fuel system
   B. There is vacuum in the vacuum lines
   C. There is electrical power to the injectors
   D. None of the above
5. When servicing the EFI system:
   A. Wear eye protection
   B. Do not reuse hose clamps
   C. Be careful of a fire hazard
   D. All of the above

ANSWERS

1: D, 2: D, 3: C, 4: A, 5: D

Unit 19 SERVICING THE FUEL SYSTEM

Some fuel system components such as the air cleaner and fuel filter are serviced as a regular part of a tune-up. Certain EFI or carburetor adjustments are also done during a complete tune-up. The overhaul or replacement of fuel system components such as the fuel pump or carburetor is normally done only when troubleshooting indicates a problem.

DEVELOPING JOB COMPETENCIES

When you finish reading and studying this unit, you should be able to:

- Remove and replace a fuel filter.
- Remove and replace an air filter element.
- Remove and replace a fuel pump.
- Remove and replace a carburetor.
- Overhaul a carburetor.
- Properly adjust a carburetion system's idle mixture, idle speed, and choke.
- Properly adjust an EFI system's idle mixture and idle speed.

REMOVAL AND REPLACEMENT OF FUEL FILTER

Clean fuel is important in any fuel system, and particularly in an EFI system, where dirt can quickly plug a fuel injector or fuel distributor. Fuel filter change intervals are specified by the vehicle manufacturer and are a regular part of a tune-up.

To change the fuel filter, first determine what type it is. All EFI systems and many carburetion systems use an in-line disposable fuel filter. Some carburetion systems use an in-line, carburetor-mounted fuel filter. Position a drain pan under the fuel filter to catch fuel as the fuel filter is removed.

WARNING: Avoid any source of ignition that could result in a fire. Follow the manufacturer's procedure to reduce EFI pressure prior to removal of the fuel filter.

In-Line Disposable Fuel Filters

Loosen and remove the *fuel filter clamps* (Figure 19-1). Remove the *fuel filter* from the *fuel lines*. Place the new fuel filter in the correct position. Replace the clamps securely.

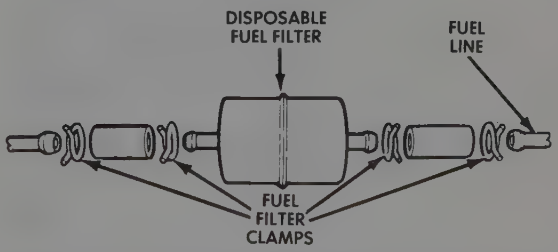


Figure 19-1. Removal and replacement of an in-line disposable fuel filter. (Courtesy of Chevrolet Motor Division, General Motors Corporation)

In-Line, Carburetor-Mounted Fuel Filters

Loosen and remove the *flare nut* (Figure 19-2) on the *fuel line* while holding the *fuel filter nut* in place. Disconnect the fuel line. Loosen and remove the fuel filter nut and remove the *filter element*.

Place the new filter element in position. Make sure that the *spring* is in place. Place the *gasket* on the fuel filter nut. Place the fuel filter nut in position and tighten until snug. Place the fuel line in position on the fuel filter nut. Tighten the flare nut on the fuel line until snug while holding the fuel filter nut in place.

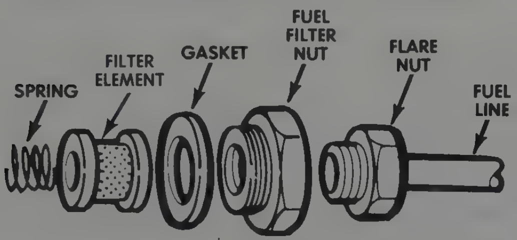
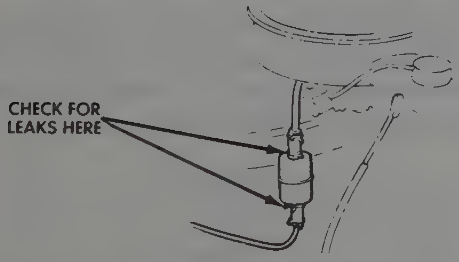
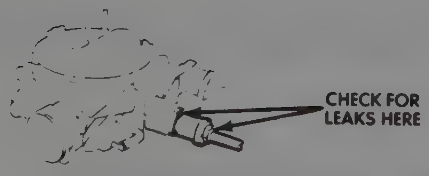


Figure 19-2. Removal and replacement of an in-line, carburetor-mounted fuel filter. (Courtesy of Chevrolet Motor Division, General Motors Corporation)

Observe the fuel filter as an assistant starts the engine. Check for any fuel leakage (Figure 19-3). If leaks occur, check clamps for tightness, or tighten the fuel filter nut and flare nut on the fuel line.



IN-LINE DISPOSABLE FUEL FILTER



IN-LINE CARBURETOR-MOUNTED FUEL FILTER

Figure 19-3. Check for fuel leakage after fuel filter installation. (Courtesy of Chevrolet Motor Division, General Motors Corporation)

REMOVAL AND REPLACEMENT OF AIR FILTER ELEMENT

Even during low speed operation, the engine pulls in a tremendous volume of air. This air has a great deal of abrasive particles which must be prevented from entering the engine. The air filter element of the air cleaner traps the abrasive particles before they can enter the engine. In so doing, however, it clogs itself. If the air filter element is not changed regularly, it can become so clogged that it limits airflow into the engine. Manufacturers specify an air filter element change interval, and the change is usually a regular part of a tune-up.

To change the air filter element, first loosen and remove the *nut*, or *wing nut*, located on top of the air cleaner (Figure 19-4). Remove the *cover* and then the *air filter element*. Place the new air filter element in the *air filter housing* (Figure 19-5). Replace the cover and tighten the wing nut until snug.

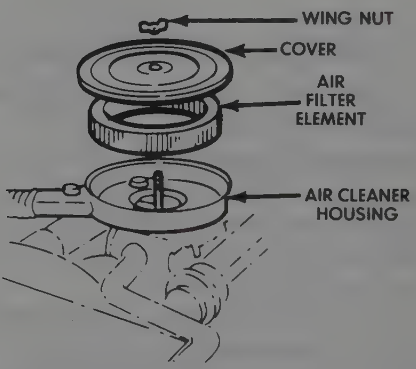


Figure 19-4. Remove the wing nut on top of the air cleaner. (Courtesy of Ford Motor Company)

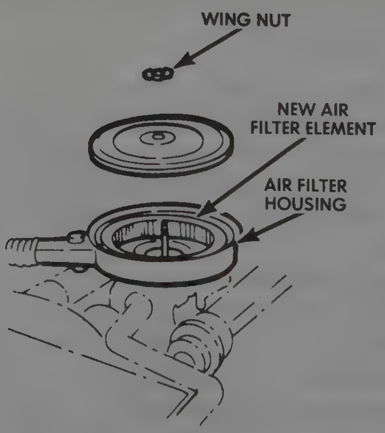


Figure 19-5. Install a new air filter element in the air cleaner housing. (Courtesy of Ford Motor Company)

REMOVAL AND REPLACEMENT OF FUEL PUMP

When fuel pump volume or pressure tests are below specifications, the fuel pump must be replaced.

WARNING: Use a container to catch fuel when the fuel lines are disconnected from the fuel pump. Always follow the manufacturer's procedure to reduce pressure in an EFI system prior to removing any fuel line. Keep fuel away from any source of ignition to avoid a fire.

Electric Fuel Pump

To replace an EFI electric fuel pump, first follow the service manual procedure to reduce the pressure in the EFI system. Disconnect the ground cable from the battery. Raise the rear portion of the vehicle with a jack, install safety jack stands, and block the wheels. Temporarily clamp the fuel line at a suitable location between the fuel tank and the electric fuel pump to prevent fuel from leaking from the tank when the fuel line is disconnected.

Unfasten the *fuel line clamps* (Figure 19-6) at the inlet and outlet sides of the *electric fuel pump*, and disengage the *fuel lines*. Remove the two *fuel pump bracket screws* securing the *fuel pump bracket*, and remove the bracket. Disconnect the fuel pump *harness connector*.

Install the new electric fuel pump. **WARNING: Do not reuse old fuel line clamps. Always use new clamps.** Connect the battery ground cable. Start the engine and check all connections for leaks.

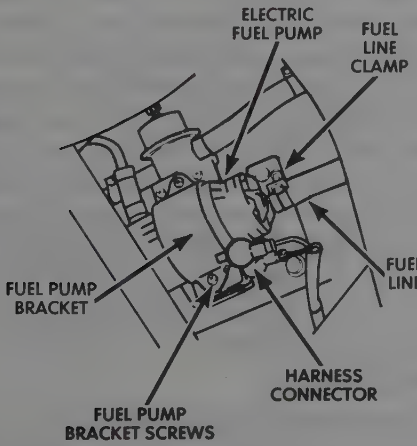


Figure 19-6. Removal and replacement of an electric fuel pump. (Courtesy of Nissan Motor Corporation in U.S.A.)

Mechanical Fuel Pump

To remove and replace a mechanical fuel pump, first disconnect the fuel inlet and outlet lines at the fuel pump. **WARNING: Always plug the fuel lines to prevent fuel spillage from causing a fire.**

Remove the fuel pump *mounting bolts, fuel pump,* and *gasket* (Figure 19-7). Install the new fuel pump, using a new gasket. Tighten the mounting bolts to specifications. *NOTE: Use sealer on the fuel pump mounting bolt threads.* Connect the fuel lines, start the engine, and check for leaks.

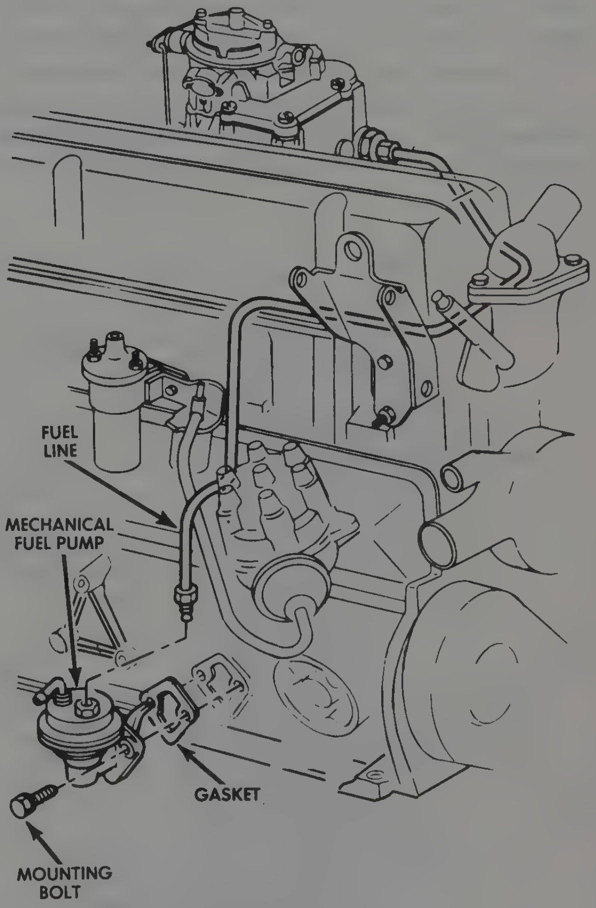


Figure 19-7. Removal and replacement of a mechanical fuel pump. (Courtesy of Chevrolet Motor Division, General Motors Corporation)

REMOVAL AND REPLACEMENT OF CARBURETOR

If troubleshooting indicates a problem in the carburetor, it must be removed for service.

WARNING: Do not attempt to remove the carburetor from the engine of a vehicle that has just been road-tested. Allow the engine to cool sufficiently. The battery cable should be removed from the negative (−) ground terminal before any fuel system component is removed. These precautions will reduce the possibility of accidental fires.

NOTE: Flooding, surging, and other performance problems are in many instances caused by dirt, water, or other foreign matter in the carburetor. To aid in diagnosing the problem, the carburetor should be carefully removed from the engine without removing the fuel from the float bowl. Its contents may be examined for contamination as the carburetor is disassembled.

To remove the carburetor, first disconnect the battery negative (−) ground cable and remove the air cleaner. Remove the fuel tank filler cap, because the fuel tank could be under a small amount of pressure. Place a container under the fuel inlet fitting to catch any fuel that may be trapped in the fuel line. Disconnect the fuel inlet line, all wiring, the throttle linkage, and all vacuum hoses. Remove the carburetor *mounting nuts* (Figure 19-8) and carefully remove the *carburetor, insulator, accelerator cable bracket, gaskets,* and *EGR support bracket* from the engine compartment.

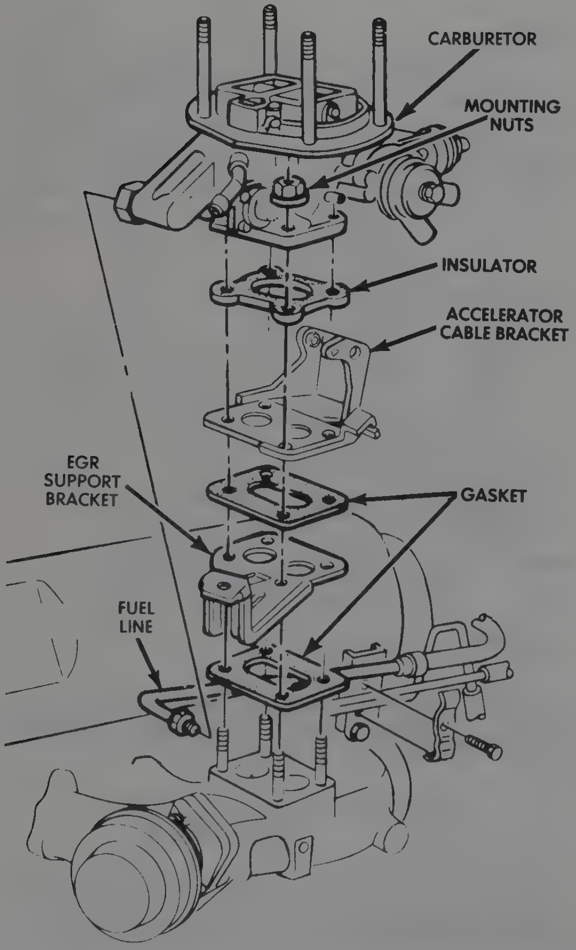


Figure 19-8. Removing a typical carburetor. (Courtesy of Chevrolet Motor Division, General Motors Corporation)

WARNING: Hold the carburetor level to avoid spilling fuel from the float bowl.

To install the carburetor, first clean the gasket mounting surfaces of the carburetor, and carefully replace the carburetor and other parts that were removed in their correct positions. Tighten the carburetor mounting nuts to torque specifications to avoid a vacuum leak. Connect the throttle linkage and fuel inlet line. Check carefully for worn or loose vacuum hose connections. Make sure that the choke plate opens and closes fully when operated. Also, make sure that full throttle travel is obtained. Install the air cleaner and connect the battery cable.

WARNING: The practice of priming an engine by pouring gasoline into the carburetor air horn after servicing should be avoided. Cranking the engine and then priming by depressing the accelerator pedal several times is adequate.

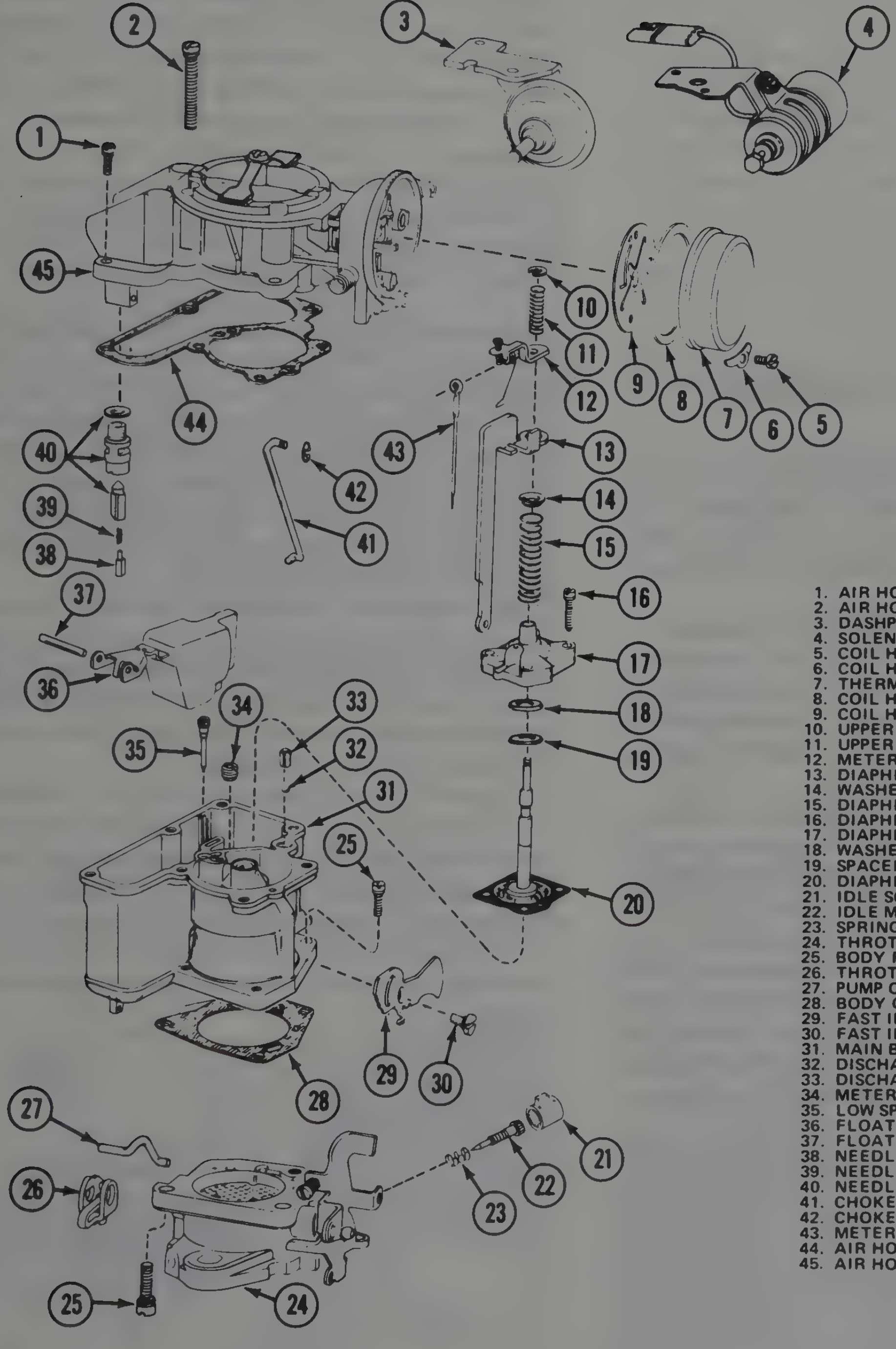
Start the engine and check for fuel leaks. Perform the adjustments described under the heading of "On-the-Car Carburetor Adjustments" later in this unit.

CARBURETOR OVERHAUL

To overhaul a carburetor, follow the step-by-step instructions provided in the appropriate service manual. An overhaul involves complete disassembly, cleaning, inspection, and, when necessary, replacement of any worn or damaged components. Carburetor overhaul kits provide the parts that typically must be replaced during an overhaul. An exploded view and a parts list, (Figure 19-9) are helpful for disassembly and reassembly. During disassembly, check the bottom of the float bowl for dirt that may have entered the fuel system.

Cleaning

After disassembly, the carburetor parts should be sorted into metallic and nonmetallic parts. Metallic carburetor parts are cleaned by soaking them in the appropriate cleaning solution



1. AIR HORN SCREW (SHORT)
2. AIR HORN SCREW (LONG)
3. DASHPOT AND BRACKET
4. SOLENOID AND BRACKET
5. COIL HOUSING SCREW
6. COIL HOUSING RETAINER
7. THERMOSTATIC COIL AND HOUSING
8. COIL HOUSING GASKET
9. COIL HOUSING BAFFLE PLATE
10. UPPER PUMP SPRING RETAINER
11. UPPER PUMP SPRING
12. METERING ROD ARM
13. DIAPHRAGM LIFTER LINK
14. WASHER
15. DIAPHRAGM SPRING
16. DIAPHRAGM HOUSING SCREW (4)
17. DIAPHRAGM HOUSING
18. WASHER
19. SPACER
20. DIAPHRAGM
21. IDLE SCREW LIMITER CAP
22. IDLE MIXTURE SCREW
23. SPRING
24. THROTTLE BODY
25. BODY FLANGE SCREW (3)
26. THROTTLE SHAFT ARM
27. PUMP CONNECTOR LINK
28. BODY GASKET
29. FAST IDLE CAM
30. FAST IDLE CAM SCREW
31. MAIN BODY
32. DISCHARGE BALL
33. DISCHARGE BALL WEIGHT
34. METERING ROD JET
35. LOW SPEED JET
36. FLOAT
37. FLOAT PIN
38. NEEDLE PIN
39. NEEDLE SPRING
40. NEEDLE, NEEDLE SEAT, GASKET
41. CHOKE CONNECTOR ROD
42. CHOKE CONNECTOR ROD RETAINER
43. METERING ROD
44. AIR HORN GASKET
45. AIR HORN

Figure 19-9. Typical exploded view of a carburetor and its parts list as found in some service manuals. (Courtesy of American Motors Corporation)

(Figure 19-10) or by cleaning them with an aerosol spray cleaner. The soaking time depends upon the strength of the cleaning solution.

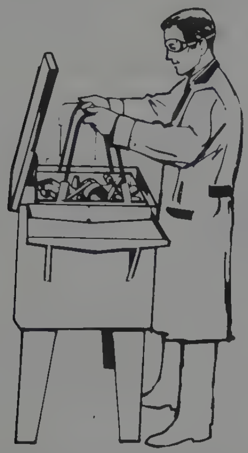


Figure 19-10. Metallic carburetor parts are cleaned by soaking them in a cold tank cleaning solution.

CAUTION: The nonmetallic parts such as the power valve, dashpots, any plastic linkage, or plastic float bowls should not be soaked. The cold tank solution can damage nonmetallic parts.

Rinse the parts with hot water after soaking to remove all traces of the cleaning solution. Dry the parts with compressed air. **WARNING: Always wear eye protection when using compressed air.** (See Unit 2, under the heading of "Using Compressed Air.")

Be sure all dirt, gum, carbon, and other foreign matter are removed. Force compressed air through all passages of the carburetor. (Again, observe the precautions discussed in Unit 2 under the heading of "Using Compressed Air.")

CAUTION: Do not use a wire brush to clean any parts or a drill or wire to clean any openings or passages in the carburetor. A drill or wire may enlarge the hole or passage, thus changing the calibration of the carburetor.

Make sure all carbon and foreign material have been removed from the choke piston housing and the choke piston. Check the operation of the choke piston to make certain it has free movement. Check the choke plate shaft for grooves, wear, and excessive looseness or binding. Inspect the choke valve or plate for nicked edges and for ease of operation. Check the throttle valve shaft in the barrel for excessive looseness or binding, and check the throttle valve for burrs that could prevent proper closure.

Shake the float to check for entry of fuel or water. If a float leaks, replace it. Check solid floats for fuel absorption by gently squeezing them. If fuel is squeezed out, replace the float. A scale is available to weigh solid floats to determine if they have absorbed fuel. Replace the float if the needle valve contact surface on the float arm is grooved. If the float system is serviceable, polish the needle valve and needle seat contact surface with crocus cloth or steel wool. Replace the float shaft if it is worn.

Replace any screws and nuts that have stripped threads. Replace all distorted or broken springs. Inspect all gasket mating surfaces for nicks and burrs. Repair or replace any parts that have a damaged gasket surface.

Adjustments. Reassemble the carburetor following the step-by-step procedure in the service manual. Install the new parts provided in the overhaul kit. A number of adjustments may be required as the carburetor is reassembled—check service manual for all adjustments. Two very important adjustments for most carburetors are the *float level adjustment* and *float drop adjustment*.

The **float level** determines how high the fuel rises in the float bowl before the float closes the needle valve against the needle seat. Too high a float level causes too-rich performance problems while too low a float level causes too-lean performance problems.

A specific procedure is provided for adjusting the float level on each model of carburetor. The float is installed along with a new needle valve and needle seat. If the float is mounted in the air horn, it is turned upside down (Figure 19-11). A *float gage* or recommended drill size is inserted between the float and air horn as shown

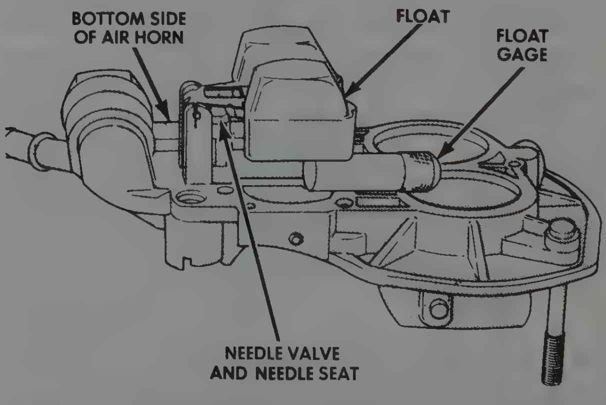


Figure 19-11. A float gage is inserted between the float and inverted air horn to check the float level. (Courtesy of Chrysler Corporation)

in Figure 19-11. If the float gage just fits, the float level is correct. If the float gage does not fit or fits too loosely, the level must be adjusted.

The float level is adjusted on many carburetors by bending the small metal *adjustment tang* on the *float* (Figure 19-12). The tang pushes on the needle valve. Bending the tang one way will cause an earlier fuel shut-off, or lower fuel level. Bending it the other way will cause a later shut-off, or higher fuel level.

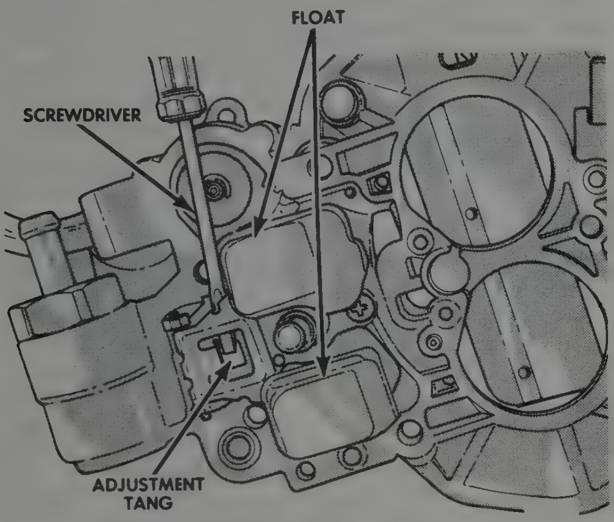


Figure 19-12. Float level is adjusted by bending the adjustment tang that contacts the needle valve. (Courtesy of Chrysler Corporation)

Another type of *float gage* is shown in Figure 19-13. The float shown is mounted in the bowl. The bowl remains right side up while the mechanic pushes down on the end of the *float arm* and measures from the top of the bowl casting to a specific part of the float, usually the *toe*. The float arm is bent to change the float setting.

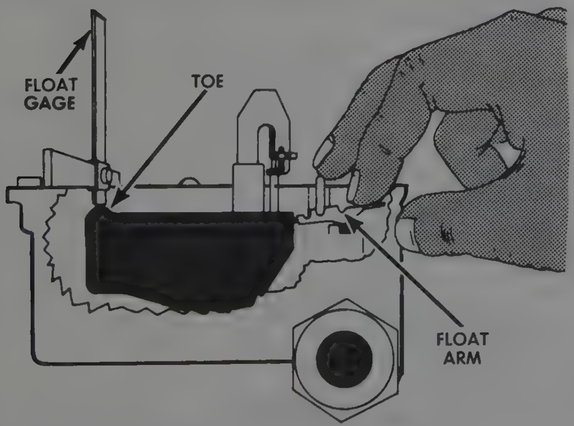


Figure 19-13. Float level adjustment on a bowl-mounted float. (Courtesy of Chevrolet Motor Division, General Motors Corporation)

The float level on some carburetors is adjusted by shims between the needle seat and the carburetor.

The **float drop** is the amount (distance) the float can lower into the float bowl. Float drop determines how far the needle valve can move out of its seat to allow fuel into the float bowl. It is measured by allowing the *float* to hang (Figure 19-14). A *float gage* is used to measure between the casting and the bottom of the float. Float drop is adjusted by bending an *adjustment tang* on the *float arm* (Figure 19-15).

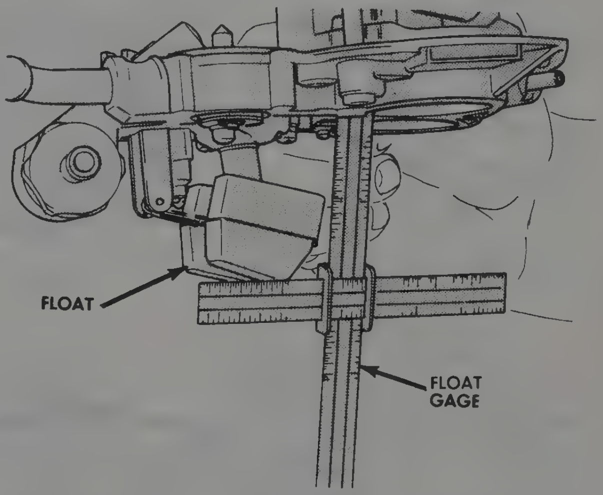


Figure 19-14. Measuring float drop with a float gage. (Courtesy of Chrysler Corporation)

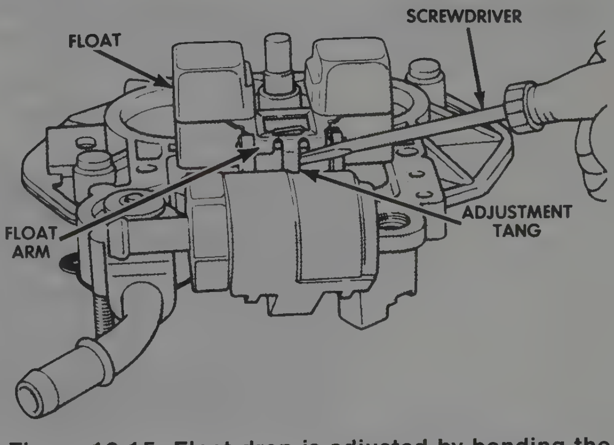


Figure 19-15. Float drop is adjusted by bending the adjustment tang on the float arm. (Courtesy of Chrysler Corporation)

After all the internal adjustments are completed, the carburetor may be reassembled and installed in the vehicle. After installation, several on-the-car adjustments must be made.

ON-THE-CAR CARBURETOR ADJUSTMENTS

After a carburetor has been serviced, or during a regular tune-up, the idle speed and idle mixture settings (discussed in Unit 16) require adjustment to meet government emission control standards. Manufacturer's specifications and recommended service procedures should be followed and accurate emission testing equipment used.

The service manual for the vehicle will show where each of the carburetor adjustments should be made. A typical carburetor adjustment locator is shown in Figure 19-16. Idle speed and idle mixture specifications are given in the service manual and on the under-the-hood decal (Figure 19-17).

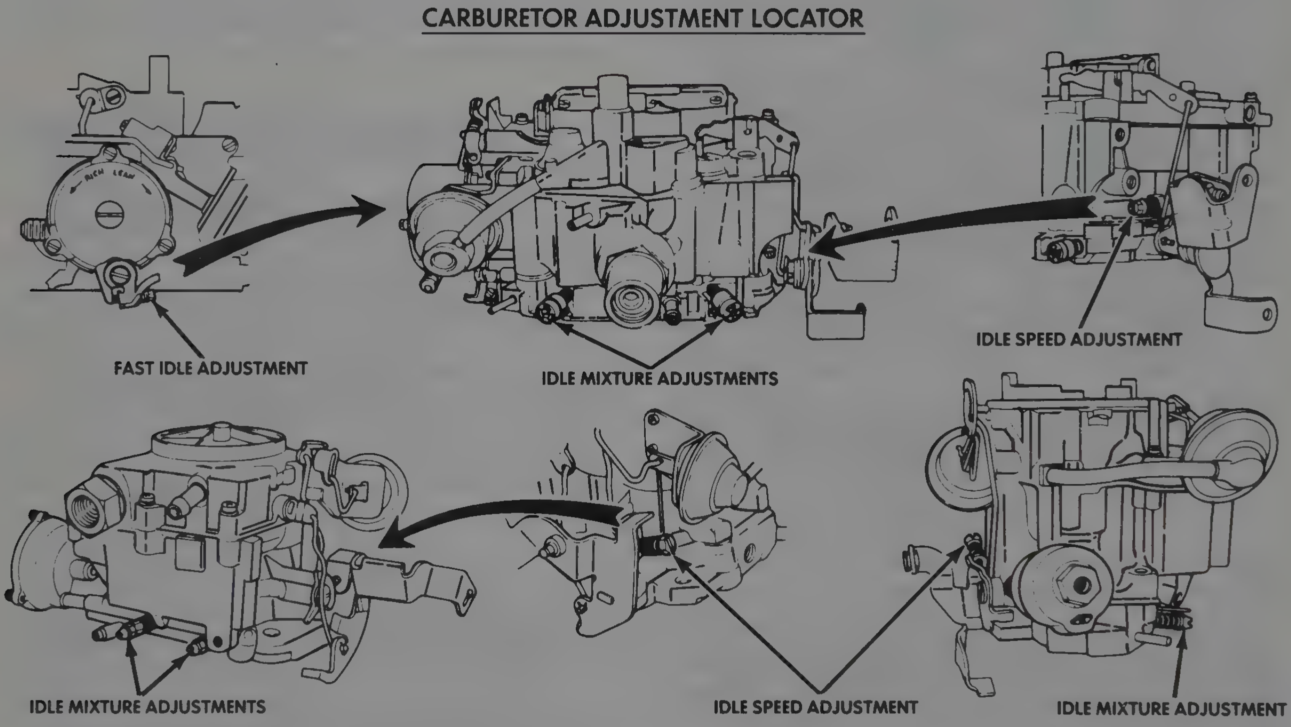
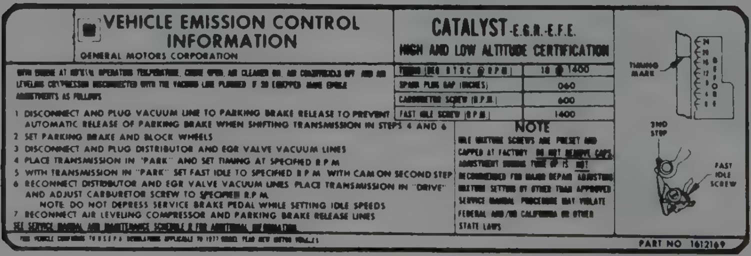


Figure 19-16. Typical carburetor adjustment locator used to determine where the carburetor adjustments should be made. (Courtesy of Chevrolet Motor Division, General Motors Corporation)


VEHICLE EMISSION CONTROL INFORMATION
GENERAL MOTORS CORPORATION

CATALYST-E.G.R.-E.F.E.
HIGH AND LOW ALTITUDE CERTIFICATION

WITH ENGINE AT NORMAL OPERATING TEMPERATURE, CHOKE OPEN, AIR CLEANER ON, AIR CONDITIONING OFF AND AIR LEVELING COMPRESSOR DISCONNECTED WITH THE VACUUM LINE PLUGGED IF SO EQUIPPED MAKE IDLE ADJUSTMENTS AS FOLLOWS

1 DISCONNECT AND PLUG VACUUM LINE TO PARKING BRAKE RELEASE TO PREVENT AUTOMATIC RELEASE OF PARKING BRAKE WHEN SHIFTING TRANSMISSION IN STEPS 4 AND 6
2 SET PARKING BRAKE AND BLOCK WHEELS
3 DISCONNECT AND PLUG DISTRIBUTOR AND EGR VALVE VACUUM LINES
4 PLACE TRANSMISSION IN "PARK" AND SET TIMING AT SPECIFIED R.P.M.
5 WITH TRANSMISSION IN "PARK" SET FAST IDLE TO SPECIFIED R.P.M. WITH CAM ON SECOND STEP
6 RECONNECT DISTRIBUTOR AND EGR VALVE VACUUM LINES. PLACE TRANSMISSION IN "DRIVE" AND ADJUST CARBURETOR SCREW TO SPECIFIED R.P.M.
NOTE DO NOT DEPRESS SERVICE BRAKE PEDAL WHILE SETTING IDLE SPEEDS
7 RECONNECT AIR LEVELING COMPRESSOR AND PARKING BRAKE RELEASE LINES

SEE SERVICE MANUAL AND MAINTENANCE SCHEDULE FOR ADDITIONAL INFORMATION

THIS VEHICLE CONFORMS TO U.S. E.P.A. REGULATIONS APPLICABLE TO 1977 MODEL YEAR NEW MOTOR VEHICLES

TIMING (DEG BTDC @ RPM)	10 @ 1400
SPARK PLUG GAP (INCHES)	.060
CARBURETOR SCREW (R.P.M.)	600
FAST IDLE SCREW (R.P.M.)	1400

NOTE
IDLE MIXTURE SCREWS ARE PRESET AND CAPPED AT FACTORY. DO NOT REMOVE CAPS. ADJUSTMENT DURING TUNE UP IS NOT RECOMMENDED. FOR MAJOR REPAIR ADJUSTING MIXTURE SETTING BY OTHER THAN APPROVED SERVICE MANUAL PROCEDURE MAY VIOLATE FEDERAL AND/OR CALIFORNIA OR OTHER STATE LAWS

PART NO 1612169

Figure 19-17. Carburetor idle speed and idle mixture specifications are given on an under-the-hood decal. (Courtesy of Chevrolet Motor Division, General Motors Corporation)

Idle Speed Adjustments

Carburetor idle speed is determined by how far the throttle valve is allowed to close. There are typically two idle speed settings: *fast idle* and *curb idle*. **Fast idle** is the setting when the choke is activated and the fast idle cam is in use during engine warm-up. **Curb idle** is the idle speed at normal operating temperature. Both settings must be checked and adjusted as necessary.

Connect a tachometer and start the engine. Observe the choke linkage to make sure the fast idle cam and linkage are working correctly. Compare the fast idle speed on the tachometer to specifications. If necessary, turn the *fast idle adjustment screw* (Figure 19-18) to attain the proper setting.

To check and adjust the curb idle, bring the engine up to normal operating temperature and attach a tachometer to the engine. Place the automatic transmission selector in NEUTRAL and set the parking brake. Set the curb idle speed to manufacturer's specifications, using the idle speed adjusting screw. A typical curb idle adjustment procedure (from a service manual) is shown in Figure 19-19.

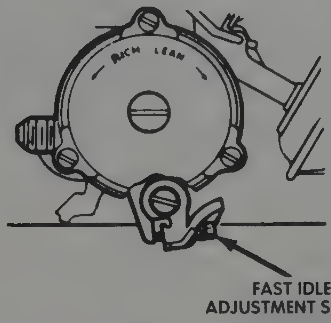

RICH LEAN
FAST IDLE ADJUSTMENT SCREW

Figure 19-18. Engine fast idle speed is adjusted with a fast idle adjustment screw. (Courtesy of Chevrolet Motor Division, General Motors Corporation)

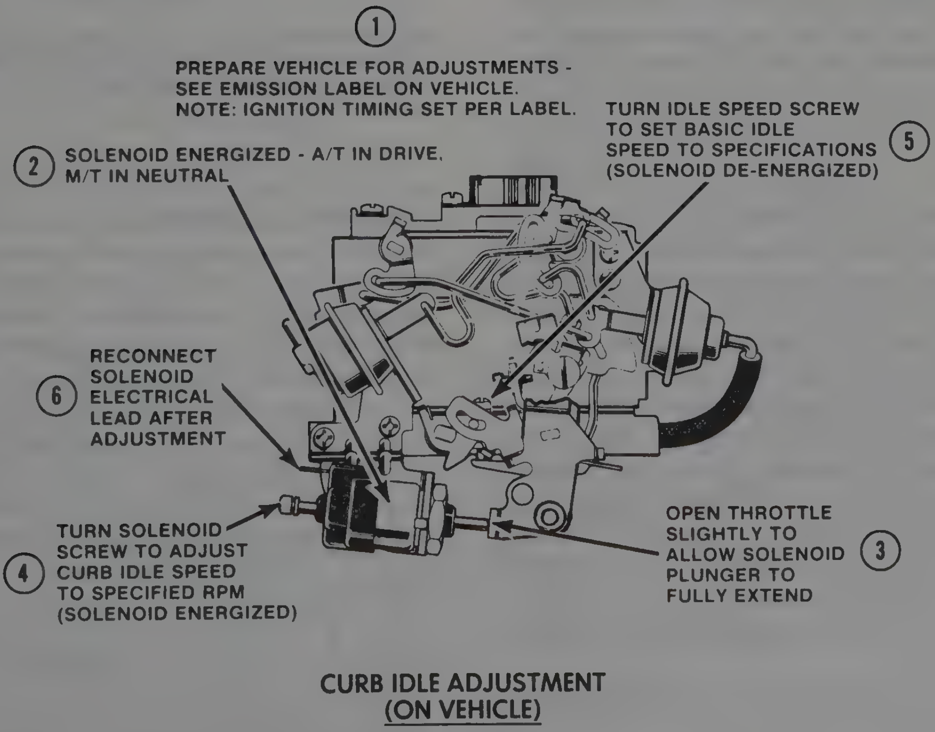

① PREPARE VEHICLE FOR ADJUSTMENTS - SEE EMISSION LABEL ON VEHICLE. NOTE: IGNITION TIMING SET PER LABEL.
② SOLENOID ENERGIZED - A/T IN DRIVE, M/T IN NEUTRAL
③ OPEN THROTTLE SLIGHTLY TO ALLOW SOLENOID PLUNGER TO FULLY EXTEND
④ TURN SOLENOID SCREW TO ADJUST CURB IDLE SPEED TO SPECIFIED RPM (SOLENOID ENERGIZED)
⑤ TURN IDLE SPEED SCREW TO SET BASIC IDLE SPEED TO SPECIFICATIONS (SOLENOID DE-ENERGIZED)
⑥ RECONNECT SOLENOID ELECTRICAL LEAD AFTER ADJUSTMENT
CURB IDLE ADJUSTMENT
(ON VEHICLE)

Figure 19-19. Typical curb idle adjustment procedure as found in a service manual. (Courtesy of Chevrolet Motor Division, General Motors Corporation)

Idle Mixture Adjustments

The idle mixture (air-fuel mixture) is adjusted with an *idle mixture screw* positioned below the carburetor *throttle valve* (Figure 19-20). The idle mixture screw has a tapered end that fits into the *idle discharge port.* Threading it *in* allows less air and fuel to enter the engine. Backing the idle mixture screw *out* allows more air and fuel to enter the engine. A single-barrel carburetor has one idle mixture screw. Two-barrel and four-barrel carburetors have two idle mixture screws.

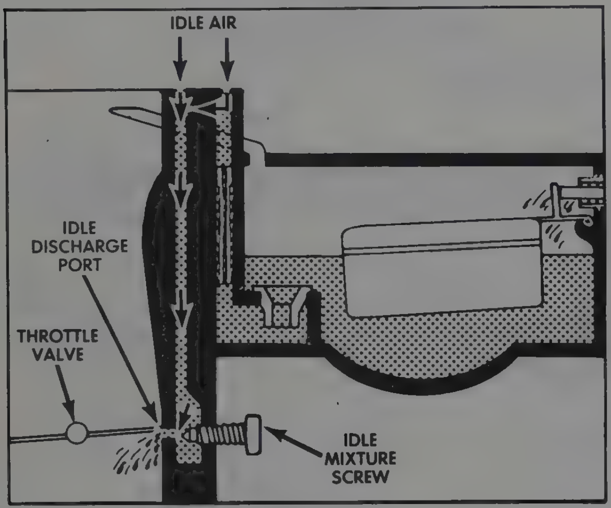


Figure 19-20. The idle mixture screw controls the amount of air and fuel for idle. (Courtesy of Chrysler Corporation)

All currently produced carburetors are equipped with idle mixture control devices called **limiter caps**, which prevent improper adjustments or alterations. They eliminate the possibility of an overly rich idle mixture adjustment. The plastic *limiter cap* shown in Figure 19-21 has a stop tab, which limits the amount of travel that the idle mixture screw can be turned. The carburetor is pre-adjusted at the factory, and idle mixture adjustments can be made only within the range of the idle limiter cap. The stop tab of the limiter cap is designed to contact the carburetor body upon rotation of the idle mixture screw. This, in effect, establishes the range of idle adjustment.

NOTE: When idle mixture adjustments are performed, an exhaust gas analyzer must be used to establish the amount of CO and HC that are emitted from the exhaust. Connect the exhaust analyzer to the vehicle according to the manufacturer's operating manual. Allow the engine to warm up to normal operating temperature.

NOTE: The idle limiter caps should not be removed from the idle mixture screw.

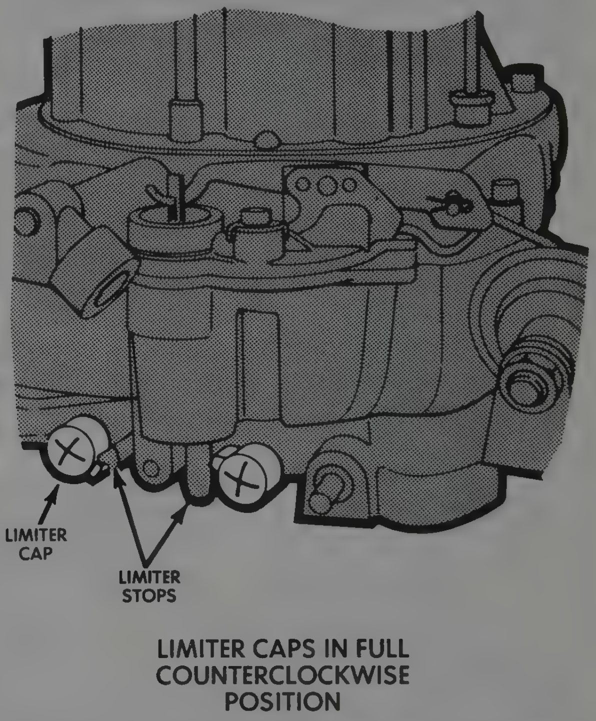

LIMITER CAP
LIMITER STOPS
LIMITER CAPS IN FULL COUNTERCLOCKWISE POSITION

Figure 19-21. Limiter caps prevent overly rich mixture adjustments. (Courtesy of Chevrolet Motor Division, General Motors Corporation)

Lean Idle Drop Method. Some manufacturers specify a *lean idle drop method* of adjusting the idle mixture. This method uses an exhaust analyzer and a tachometer. The tachometer is observed for a change in idle RPM as a guide to adjusting the air-fuel mixture. Idle speed is set to specificiations and the idle mixture adjusted to a rich setting. The idle mixture screw is then turned *out* to a "lean roll" condition (when the engine speed drops about 20 RPM). Next, the idle mixture screw is turned *in* about one-half turn to enrich the air-fuel mixture. This procedure is followed on the other idle mixture screw if the carburetor has more than one barrel. Balance is thus established on the two sides of a two-barrel or four-barrel carburetor.

NOTE: Do not observe the exhaust analyzer while making this adjustment. Wait about ten seconds for the analyzer to stabilize.

If the CO level is at or below the specifications on the under-the-hood label, and if there is no lean misfire, the adjustment is complete. If the CO is higher than specifications, lean the mixture by turning the idle mixture screws in about one-eighth turn at a time until the mixture is within specifications.

NOTE: Be sure to wait ten seconds each time before reading the analyzer.

The taper on the idle mixture screw determines the amount the screw must be turned to produce an emissions change. A long taper requires more turns than a short taper. In some cases a one-sixteenth turn will change the CO reading as much as .5 to 1%.

Propane Enrichment Method. On many late-model vehicles that are equipped with a catalytic converter, it is not possible to adjust the carburetor idle mixture using an exhaust gas analyzer. To catalytic converter effectively burns up the HC and CO before it exits the tail pipe. Some catalytic converters work so well that even when a spark plug is misfiring, no emissions register on the analyzer.

To properly adjust the air-fuel mixture on this type of vehicle, the technician uses a *propane (or artificial) enrichment method.* A *bottle of propane gas* and a *connecting hose* with a *control valve* are required for this method (Figure 19-22). The control valve on the connecting hose is screwed into the propane bottle. The other end of the connecting hose is attached to the *vapor line fitting* in the *air cleaner.*

The exact steps of the propane enrichment method vary from one vehicle to another, so be sure to follow the correct procedure for the particular vehicle being serviced. In general, the method can be summarized as follows:

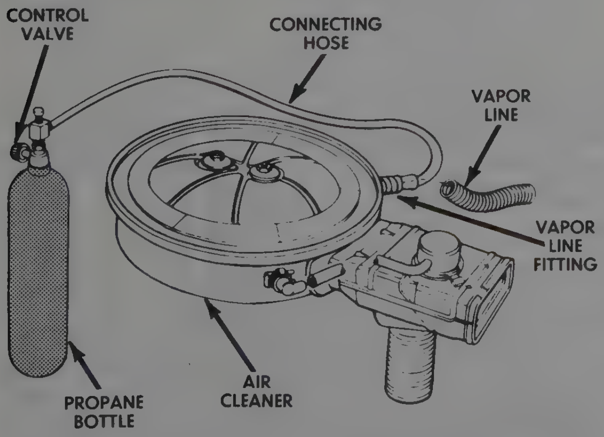


Figure 19-22. Propane enrichment (artificial enrichment) method of adjusting the idle mixture. (Courtesy of Chevrolet Motor Division, General Motors Corporation)

Propane gas is metered into the air cleaner at idle speed. The tune-up technician observes a tachometer to see how much the idle speed is increased. (The speed change associated with propane-assisted idle adjustments is often called the **delta RPM**.) If the increase is within the range specified on the under-the-hood label, the air-fuel mixture is correct, and no carburetor adjustment is necessary. If the increase is above or below specifications, adjust the idle mixture and/or the idle speed.

Choke Adjustments

The automatic choke should be checked for proper adjustment after a carburetor is overhauled or anytime troubleshooting procedures indicate an overly rich air-fuel mixture. Choke operation is adjusted by varying the tension on the thermostatic spring.

WARNING: Be extremely careful when operating an engine with the air cleaner housing removed. Some engines become so leaned out when the air cleaner is removed, that a backfire is caused, resulting is possible injury or fire.

Piston-type Automatic Chokes. On piston-type automatic chokes (Figure 19-23), *index marks* are scribed on the *housing cover* and the *housing body*. Loosen the retaining screws and rotate the housing cover in the *lean* or *rich* direction to line up the index marks. A specification that calls for the choke to be set on "index" means that the index mark on the housing cover should be aligned with a corresponding index mark on the housing body.

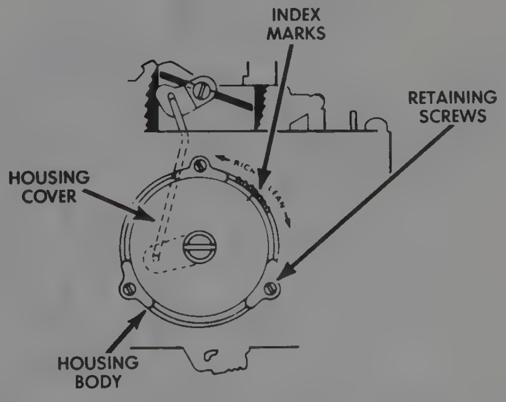


Figure 19-23. Piston-type automatic choke. (Courtesy of Chevrolet Motor Division, General Motors Corporation)

Vacuum Break or Well-type Automatic Choke. Adjustment of a vacuum break or well-type choke (Figure 19-24) is usually made by bending a *choke lever* or the *rod* that attaches the *thermostatic spring* to the *choke plate* (Figure 19-24). Remove the upper end of the rod from the choke lever and hold the choke valve open. Check the relationship of the end of the rod with its hole in the choke lever. (Specifications may be given as one rod diameter above or below the hole or as a sliding fit of the link in a choke lever slot.) Bend the rod or choke lever to specifications.

NOTE: The thermostatic spring, mounted in the manifold well, has index marks on it similar to those on a piston-type automatic choke. Some thermostatic springs have an adjustment nut to allow spring tension to be changed. A few vehicle manufacturers give adjustment specifications for these springs, but these marks are usually for original factory settings, not for field service.

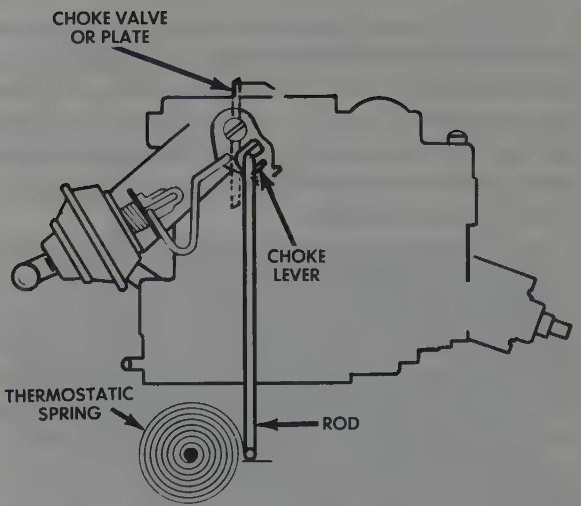

CHOKE VALVE OR PLATE
CHOKE LEVER
THERMOSTATIC SPRING
ROD

Figure 19-24. Well-type automatic choke. (Courtesy of Chevrolet Motor Division, General Motors Corporation)

ON-THE-CAR EFI ADJUSTMENTS

Idle speed and idle mixture specifications for EFI vehicles are given in the service manual and on the under-the-hood label.

Idle Speed Adjustments

Idle speed is measured with a tachometer while idle mixture is measured with the help of an infrared exhaust analyzer. As described in Unit 17, the *throttle chamber* (Figure 19-25), located between the *airflow meter* and the *intake manifold*, is equipped with a *throttle valve*. It controls the intake airflow in response to accelerator pedal movement. The rotary shaft of the throttle valve is connected to the *throttle valve switch*. The throttle valve remains closed during engine idling, and the air required for idling passes through the *idle speed bypass port* (or *channel*) into the *intake manifold*.

Idle speed adjustment is made by the *idle speed screw* (Figure 19-25) located in the bypass port or channel. There is another bypass line, the *air regulator bypass channel*, in the throttle chamber to pass air through the *air*

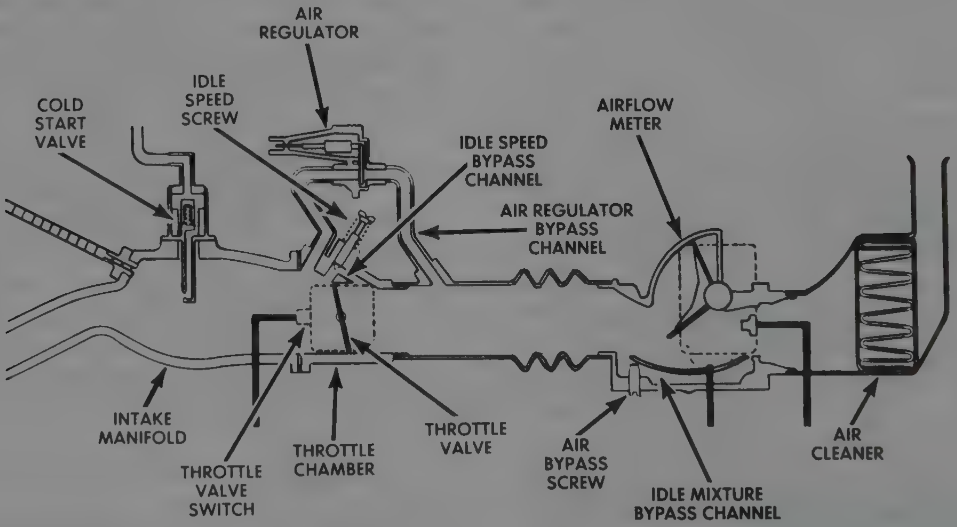

AIR REGULATOR
IDLE SPEED SCREW
COLD START VALVE
AIRFLOW METER
IDLE SPEED BYPASS CHANNEL
AIR REGULATOR BYPASS CHANNEL
INTAKE MANIFOLD
THROTTLE CHAMBER
THROTTLE VALVE
AIR BYPASS SCREW
AIR CLEANER
THROTTLE VALVE SWITCH
IDLE MIXTURE BYPASS CHANNEL

Figure 19-25. The idle speed screw regulates the amount of air that bypasses the throttle valve during idle operation. (Courtesy of Nissan Motor Corporation in U.S.A.)

regulator into the intake manifold during engine warm-up.

Start the engine and allow it to reach operating temperature. Connect a tachometer to the ignition system. Use the *idle speed screw* to set the idle speed to specifications (Figures 19-25 and 19-26).

WARNING: On automatic transmission models this adjustment must be performed with the vehicle in DRIVE. Observe all the necessary safety precautions. Also, if the vehicle is equipped with air conditioning, make sure it is turned off.

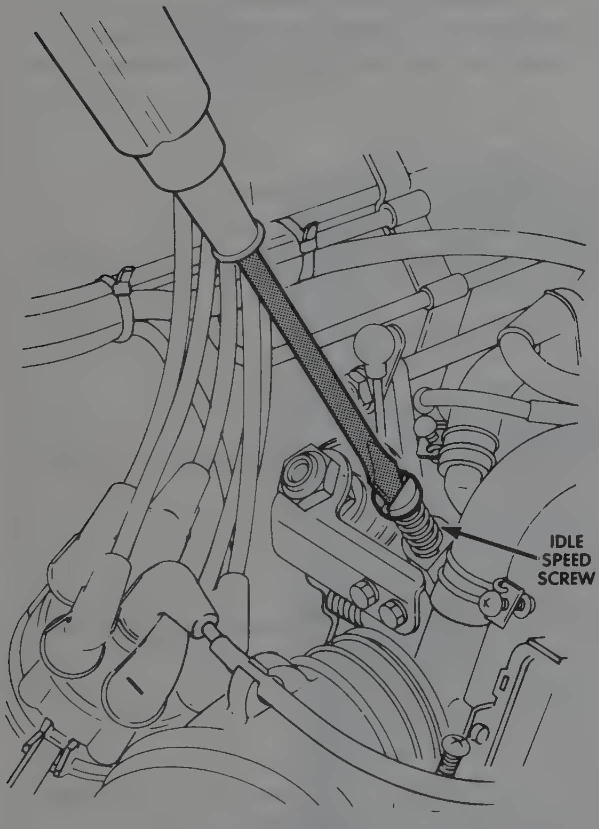


Figure 19-26. Adjusting the idle speed by turning the idle speed screw. (Courtesy of Nissan Motor Corporation in U.S.A.)

Idle Mixture Adjustments

As in carbureted engines, idle mixture in an EFI engine has a great deal to do with low emissions, smooth idle, and surge-free cruising. Therefore, the idle CO percent should be adjusted and checked during a tune-up.

When the engine is idling, the amount of air that passes through the airflow meter is extremely small. Idle air flows parallel with the *compensating flap* (Figure 19-27), through the *bypass channel*. An *air bypass screw* or *idle mixture screw* regulates the amount of air routed through the bypass channel. The amount of air determines the percentage of CO in the exhaust.

If the CO percent is not within specifications, remove the *plastic plug* (Figure 19-28) from the airflow meter to gain access to the air bypass screw. Turn it *clockwise* to richen the mixture and *counterclockwise* to lean the mixture. Recheck and, if necessary, readjust the idle speed screw.

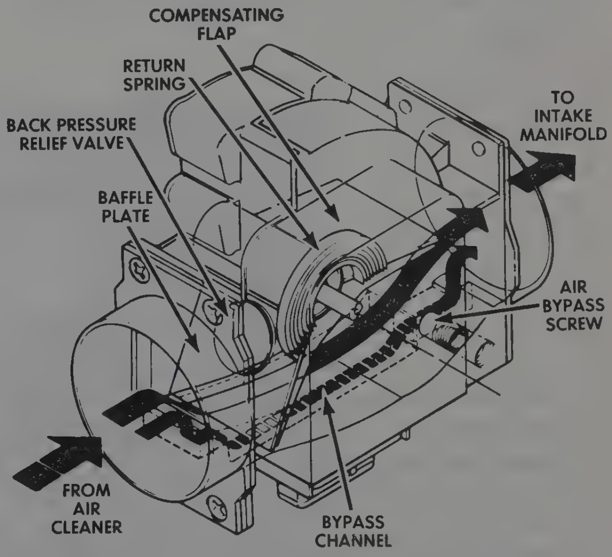


Figure 19-27. Air for idle is bypassed around the airflow meter baffle plate, through the bypass channel. (Courtesy of Nissan Motor Corporation in U.S.A.)

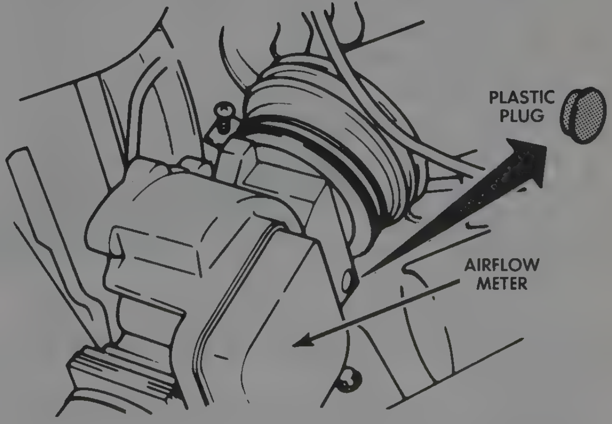


Figure 19-28. The idle mixture is adjusted by removing a plastic plug and turning the idle mixture screw or air bypass screw. (Courtesy of Nissan Motor Corporation in U.S.A.)

KEY TERMS

Curb idle: Idle speed at normal engine operating temperature.

Delta RPM: The speed change associated with propane-assisted idle adjustments.

Fast idle: Idle speed when the choke is activated during engine warm-up.

Float drop: The amount (distance) a float can lower in the float bowl.

Float level: The adjustment that determines how high the fuel rises in the float bowl before the float closes the needle valve against the needle seat.

Limiter caps: Idle mixture control devices that limit the amount of idle mixture screw travel.

SELF-CHECK

1. Why is it important to change the fuel filter?
2. Describe how to change an in-line disposable fuel filter.
3. Why is it important to change the air filter element?
4. Why must EFI pressure be reduced before removing a fuel line?
5. Why should the fuel be left in the float bowl when a carburetor is removed?
6. How are the nonmetallic parts of a carburetor cleaned?
7. How can a solid float be checked for fuel absorption?
8. Why is it bad practice to clean out carburetor passages with a drill or wire brush?
9. How is the carburetor float level measured and adjusted?
10. How is the carburetor float drop measured and adjusted?
11. How is idle speed on a carburetor adjusted?
12. How is idle mixture on a carburetor adjusted?
13. How is a well-type automatic choke adjusted?
14. How is EFI idle speed adjusted?
15. How is EFI idle mixture adjusted?

DISCUSSION TOPICS AND ACTIVITIES

1. Disassemble and reassemble several different models of shop carburetors.
2. Make all the required *on-the-car adjustments* to a fuel system.

CERTIFICATION PRACTICE

1. A carbureted engine is running too rich. Mechanic A says the float level may be too high. Mechanic B says the float level may be too low. Who is correct?
   A. Mechanic A
   B. Mechanic B
   C. Both mechanic A and B
   D. Neither mechanic A nor B
2. Typical on-the-car carburetor adjustments include:
   A. Idle speed
   B. Idle mixture
   C. Choke
   D. All of the above
3. Typical on-the-car EFI adjustments include:
   A. Idle mixture
   B. Idle speed
   C. Both A and B
   D. Neither A nor B
4. The EFI idle speed screw is located on the:
   A. Airflow meter
   B. Throttle chamber
   C. Speed switch
   D. Pressure regulator
5. The EFI idle mixture screw or air bypass screw is located on the:
   A. Airflow meter
   B. Throttle chamber
   C. Speed switch
   D. Pressure regulator

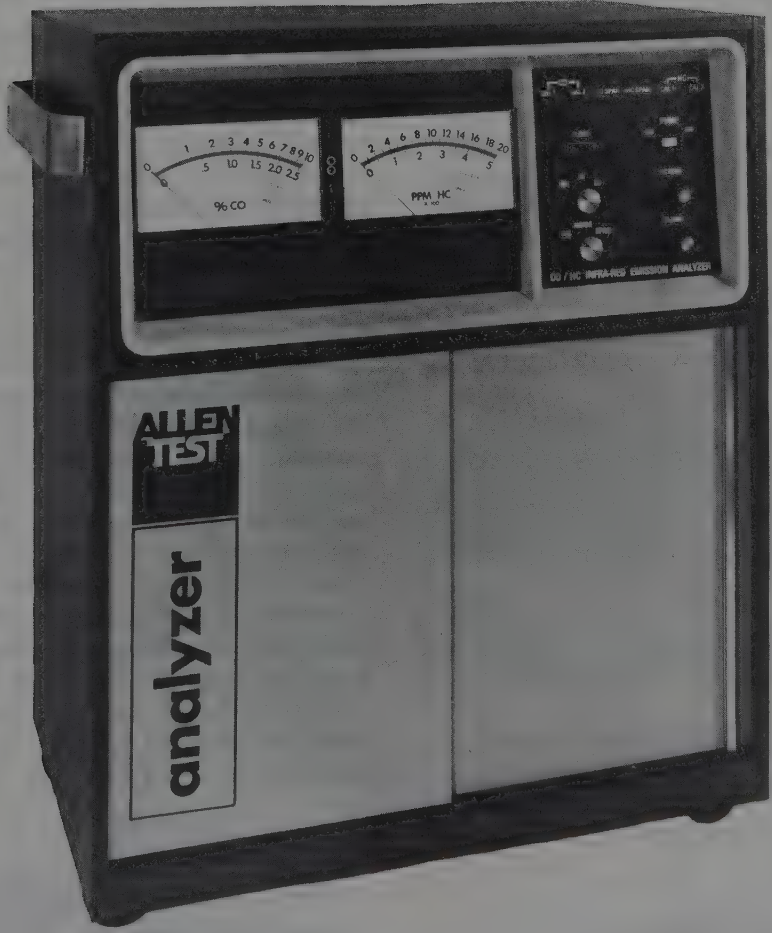
ANSWERS

1: A, 2: D, 3: C. 4: B, 5: A

SECTION VI

Emission Control System

Unit 20. Emission Control System Operation
Unit 21. Troubleshooting the Emission Control System
Unit 22. Servicing the Emission Control System


% CO
PPM HC
CO / HC INFRA-RED EMISSION ANALYZER
ALLEN TEST
analyzer

Unit 20

EMISSION CONTROL SYSTEM OPERATION

The purpose of the emission control system is to eliminate air pollution or reduce it to an acceptable level. Most of the devices used to control emissions have a direct effect on engine operation. Since the purpose of a tune-up is to restore engine power and fuel mileage while reducing emissions, the operation of the emission system and how it relates to the ignition system and fuel system must be understood.

DEVELOPING JOB COMPETENCIES

When you finish reading and studying this unit, you should be able to:

- Describe the different automotive emissions and the operating conditions that produce them.
- Explain how crankcase emissions are controlled.
- Describe the parts and operation of the evaporation control system.
- Describe the purpose of the exhaust gas recirculation system.
- Identify and explain the purpose of ignition timing controls.
- Explain the purpose of the common carburetor emission equipment.
- Describe the operation of a heated intake air system.
- Describe the parts and operation of an air injection system.
- Describe how a catalytic converter works.
- Explain the purpose of a feedback system.

AUTOMOTIVE EMISSIONS

An automobile engine develops three significant air pollutants: *carbon monoxide, hydrocarbons,* and *oxides of nitrogen*. It also contains small amounts of solid matter, called *particulates*, made up largely of lead compounds from the *tetraethyl lead* that is used to increase the octane rating of gasoline.

Carbon Monoxide

An insufficient amount of oxygen in the air-fuel mixture results in incomplete combustion. Incomplete combustion in turn produces **carbon monoxide** (abbreviated CO). High CO emission levels can be caused by incorrect carburetor adjustments or by anything that restricts airflow to the combustion chamber, such as a dirty air filter or restricted carburetor air bleeds.

WARNING: Carbon monoxide (CO) is a tasteless, odorless, and deadly gas. Inhaling a high concentration of CO in a closed space or area can be fatal. This is why engines should be operated only in well-ventilated areas.

Hydrocarbons

Incomplete combustion results in **hydrocarbons** (abbreviated HC) as well as carbon monoxide. Hydrocarbons also result from vapors escaping from the crankcase or fuel system. These HC emissions are unburned or partially burned fuel. Excessive hydrocarbons in the exhaust indicate that the engine is misfiring because of a mechanical or ignition problem, or that carburetion is not properly balanced and the air-fuel mixture is too rich or too lean.

If the air-fuel mixture is too rich, there is not enough air (oxygen) in the combustion chamber to burn all the gasoline. If the air-fuel mixture is too lean, it may produce a weak fire in the combustion chamber that is extinguished before all the gasoline is burned. In either case, unburned hydrocarbons go out through the tail pipe.

Hydrocarbons are normally harmless and invisible, but when they are held in suspension and subjected to sunlight, they can combine with oxides of nitrogen (discussed next in this unit) to form photochemical smog. In heavy concentrations, photochemical smog causes irritation in the eyes and nose.

Oxides of Nitrogen

When combustion temperatures reach high levels, **oxides of nitrogen** (abbreviated NO_x) are formed. The temperature levels necessary to produce NO_x vary depending on engine and cylinder head design. Oxygen and nitrogen do not combine chemically unless they are subjected to very high temperatures. The "x" in NO_x means that a molecule of nitrogen may combine with more than one molecule of oxygen to form NO_2, NO_3, NO_4, and so on.

NO_x is also formed as part of the overall combustion process. It increases as combustion temperatures increase. No_x can combine with unburned hydrocarbons in the atmosphere to produce photochemical smog.

Particulates

Extremely small particles of lead occuring as solid matter in the exhaust are **particulates.** They are only a small part of the total pollutants. The use of *unleaded* or *no-lead gasoline* substantially reduces the amount of particulates in engine exhaust.

ENGINE OPERATION AND EMISSIONS

Three sources of polluting emissions are the exhaust, the crankcase vapors, and fuel evaporation (Figure 20-1). Exhaust emissions account for approximately 60% of the pollution produced by an automobile, crankcase vapors account for about 20%, and fuel evaporation accounts for about 20%.

Emissions would be relatively simple to control if all driving were done on the open highway at one constant speed. However, mixtures of air and fuel that are correct for complete combustion at steady highway speeds are not rich enough to keep the engine from stalling at idle speed or when the engine is under acceleration. For smooth engine performance, the air-fuel ratio must be constantly adjusted to meet constantly changing driving conditions.

During heavy engine load, the engine needs a rich air-fuel mixture to produce maximum power. Since there is not enough oxygen to burn all the fuel, hydrocarbon emissions increase.

During decleration the throttle valve (plate) snaps shut. Manifold vacuum rapidly increases.

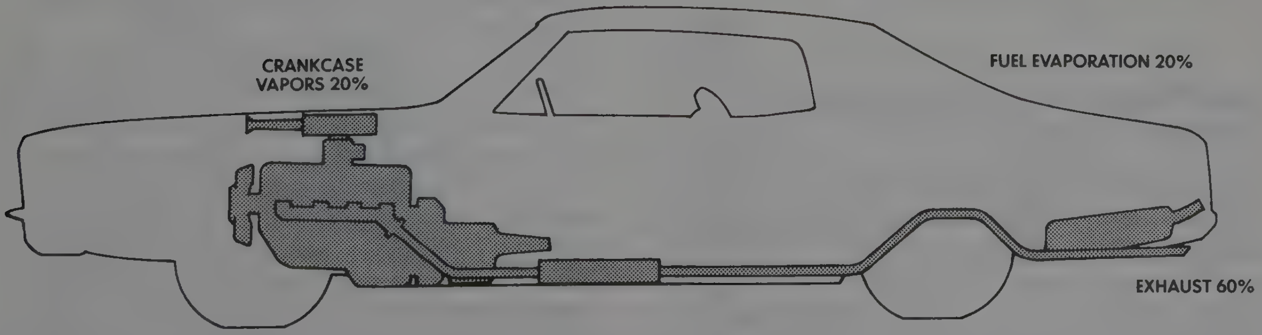


Figure 20-1. Three sources of automobile emissions that are pollutants. (Courtesy of Chevrolet Motor Division, General Motors Corporation)

Liquid fuel on the intake manifold walls vaporizes, or boils off, in a process called *flash vaporization*. The vaporized fuel enters the combustion chambers and increases hydrocarbon emissions.

Combustion chamber shape and temperature affect hydrocarbon formation. If the flame does not reach all the fuel in the combustion chamber during combustion, that fuel will leave the combustion chamber as unburned hydrocarbons. Also, if the combustion chamber is too cold, the fuel will not ignite and will leave the combustion chamber as unburned hydrocarbons.

Any kind of cylinder misfire can cause a high hydrocarbon emission. If there is no spark, or a poor spark, the air-fuel mixture will not ignite in the cylinder. A defective carburetor or a vacuum leak may produce an air-fuel mixture too lean to burn, producing the same effect. In either case, excessive hydrocarbons go out the tail pipe. Generally, the lower the HC emission is, the better the engine is running.

During heavy load or deceleration, a rich air-fuel mixture is produced. Whenever there is a richer than normal air-fuel mixture, carbon monoxide (CO) emissions increase. Excessive CO levels are almost always caused by faulty carburetion or EFI systems and are never produced by cylinder misfire. No burning occurs during misfire, and CO is produced only by *partial (incomplete) burning*.

Oxides of nitrogen (NO_x) are formed just after combustion. They are most likely to form when combustion temperatures and pressures are high. Controlling NO_x is difficult, because lowered combustion temperature or pressures results in lowered engine efficiency. As HC and CO formation is limited, the engine's NO_x output goes up. Conversely, most methods of limiting NO_x cause an increase in HC and CO and a decrease in engine efficiency.

CONTROLLING CRANKCASE EMISSIONS

During the combustion process, a highly corrosive gas is produced. Also, for every gallon of gasoline burned, more than a gallon of water is formed. During the last part of the combustion stroke, some of the unburned fuel (HC) and products of combustion leak past the piston rings into the crankcase. This leakage is called *blow-by*. The blow-by must be removed before it condenses in the crankcase and reacts with the oil to form sludge. If circulated with the oil, sludge will cause corrosion and accelerated wear of pistons, rings, valves, and bearings. Because blow-by also carries with it a certain quantity of unburned fuel (HC), it must not be allowed to escape to the atmosphere outside the engine.

These harmful gases are removed from the crankcase through a **positive crankcase ventilation (PCV) system** (Figure 20-2) utilizing engine vacuum to draw fresh air through the *crankcase*. An *air intake hose* is connected between the *air cleaner* and a sealed *oil filler cap* covering an opening in the *valve cover* (also called *rocker arm cover*).

Under normal engine operating conditions, air enters the crankcase through the air intake hose connected to the carburetor air cleaner. Under heavy acceleration conditions, excess vapors from the crankcase flow back up through the air intake hose and are mixed with the air entering the carburetor from the outside (intake air). In this way, the vapors are reburned in the combustion chamber.

PCV Valve

A *positive crankcase ventilation (PCV) valve* (Figure 20-2) is used to control the rate at which vapors are allowed to return to the intake manifold of the engine, where they are ignited with the air-fuel mixture. The PCV valve meters the flow through the system according to various modes of operation such as idle, cruise, and acceleration.

The PCV valve is an assembly (Figure 20-3) that consists of a *spring* and *plunger* mounted in a *housing*. Intake manifold vacuum and spring tension are used to position the plunger. The plunger position in turn regulates crankcase vapor flow.

During periods of deceleration and idle (Figure 20-3), manifold vacuum is high. This high vacuum overcomes the tension of the PCV valve spring, and the plunger bottoms in the manifold vacuum end of the PCV valve housing. Because of the shape of the plunger, it restricts but does not completely stop the flow of crankcase vapors to the intake manifold.

When the engine is lightly accelerated or operated at constant or cruise speed (Figure 20-3), intake manifold vacuum is less than at

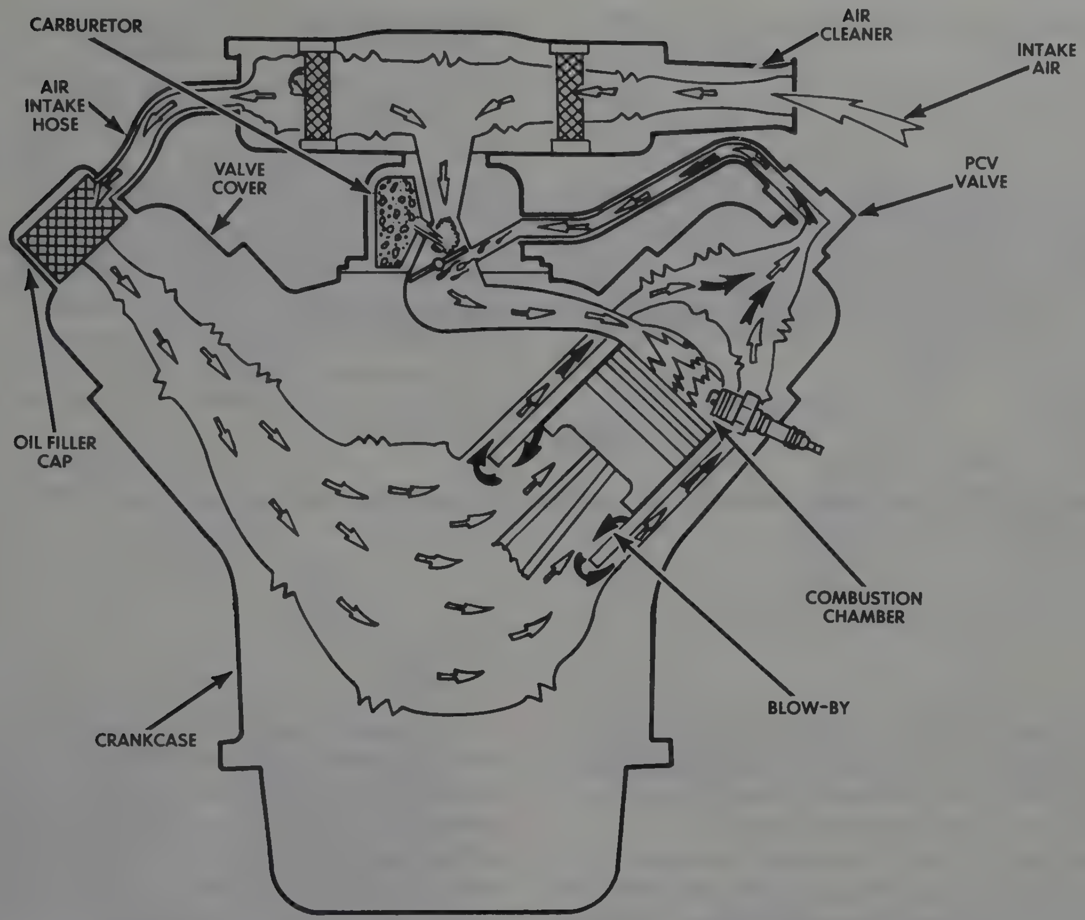

CARBURETOR
AIR CLEANER
INTAKE AIR
AIR INTAKE HOSE
VALVE COVER
PCV VALVE
OIL FILLER CAP
COMBUSTION CHAMBER
BLOW-BY
CRANKCASE

Figure 20-2. Typical positive crankcase ventilation (PCV) system. (Courtesy of Chrysler Corporation)

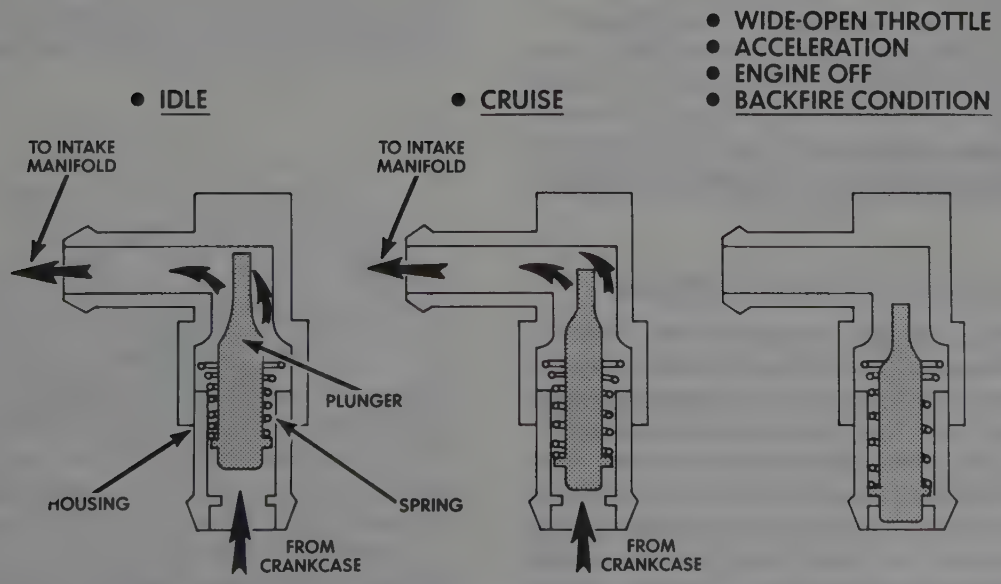

• IDLE
• CRUISE
• WIDE-OPEN THROTTLE
• ACCELERATION
• ENGINE OFF
• BACKFIRE CONDITION
TO INTAKE MANIFOLD
TO INTAKE MANIFOLD
PLUNGER
HOUSING
SPRING
FROM CRANKCASE
FROM CRANKCASE

Figure 20-3. PCV valve operation. (Courtesy of Chrysler Corporation)

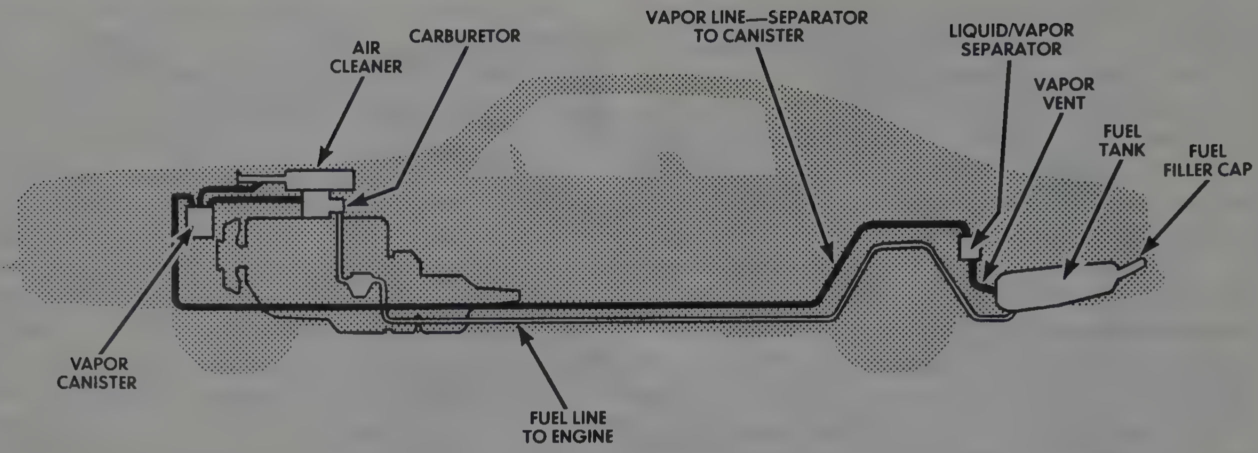


Figure 20-4. Typical evaporation control system. (Courtesy of Chevrolet Motor Division, General Motors Corporation)

idle. During this time, spring tension equals the vacuum pull, and the plunger assumes a mid-position in the housing. Most vapors can now flow into the intake manifold.

During wide-open throttle and acceleration (Figure 20-3), manifold vacuum is low. The low vacuum cannot overcome the spring tension, and the plunger remains seated (the PCV valve remains closed). The PCV valve also remains closed when the engine is turned off and if the engine backfires (Figure 20-3).

In the event of an engine backfire, the PCV valve plunger is forced back and seated against the inlet of the housing. This prevents the backfire from traveling through the PCV valve and into the crankcase. If the backfire entered the crankcase, it could ignite the volatile blow-by gases, causing the crankcase to explode.

CONTROLLING FUEL VAPORS

The function of the **evaporation control system** (Figure 20-4) is to prevent gasoline vapors (hydrocarbons) from escaping into the atmosphere from the *fuel tank* and *carburetor*. When fuel evaporates in the carburetor float bowl or fuel tank, the vapor's pass through vent hoses or tubes to a *vapor canister*, where they are temporarily held until they can be drawn into the intake manifold when the engine is running.

The system uses a sealed fuel tank having a series of vent lines that lead to a *liquid/vapor separator* and then on to a *vapor canister*, sometimes called *carbon canister*, filled with activated charcoal and connected to the carburetor. The *fuel filler cap* is normally not vented to the atmosphere but is fitted with a valve that allows both pressure and vacuum relief.

At times, usually when the fuel tank is full, liquid fuel enters the vent lines along with the vapors. The *liquid/vapor separator* permits the vapors to pass on to the vapor canister while the liquid fuel is returned to the fuel tank.

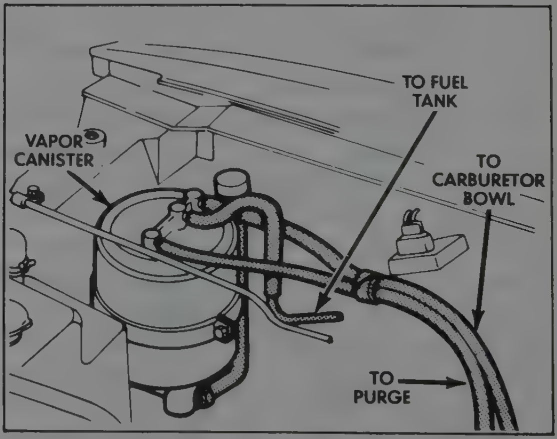


Figure 20-5. The vapor canister is mounted in the engine compartment. (Courtesy of Chrysler Corporation)

When fuel evaporates, the vapors flow through the lines from the liquid/vapor separator to the vapor canister located in the engine compartment (Figure 20-5). A cross section of a typical vapor canister is shown in Figure 20-6. Here the vapors are absorbed (storing vapor) by the bed of *activated charcoal*. This occurs mostly when the engine is not running. When the engine is operated, the vapor canister releases vapors. Along with fresh air, the vapors are drawn up into the carburetor and to the combustion chamber. The vapor canister is purged by fresh air drawn through its bottom. Air entering the vapor canister passes through a *fiberglass filter*.

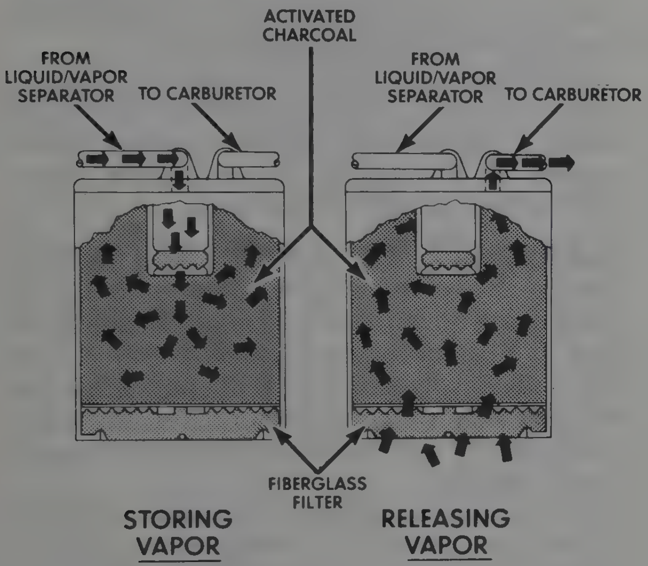

ACTIVATED CHARCOAL
FROM LIQUID/VAPOR SEPARATOR
TO CARBURETOR
FROM LIQUID/VAPOR SEPARATOR
TO CARBURETOR
FIBERGLASS FILTER
STORING VAPOR
RELEASING VAPOR

Figure 20-6. Cross section of a vapor canister. (Courtesy of Chevrolet Motor Division, General Motors Corporation)

CONTROLLING EXHAUST EMISSIONS

Emissions that leave the engine through the exhaust pipe are the most difficult to control. A variety of engine modifications and control systems have been devised to control exhaust emissions. As federal and state emission standards have increased, the number and types of these control systems have increased. The most common types are discussed here.

Exhaust Gas Recirculation System

A system used on many engines to reduce oxides of nitrogen is the **exhaust gas recirculation (EGR) system** (Figure 20-7). Oxides of nitrogen are reduced by lowering the peak flame temperatures in the combustion chamber. This is accomplished by allowing a controlled amount of *exhaust gas* (Figure 20-8) to recirculate and enter the *intake manifold*, where it dilutes the incoming air-fuel mixture.

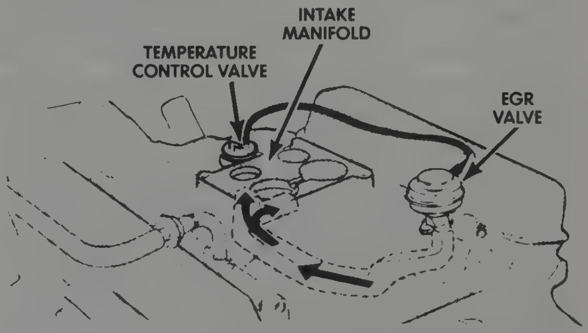

INTAKE MANIFOLD
TEMPERATURE CONTROL VALVE
EGR VALVE

Figure 20-7. Typical EGR (exhaust gas recirculation) system. (Courtesy of Chevrolet Motor Division, General Motors Corporation)

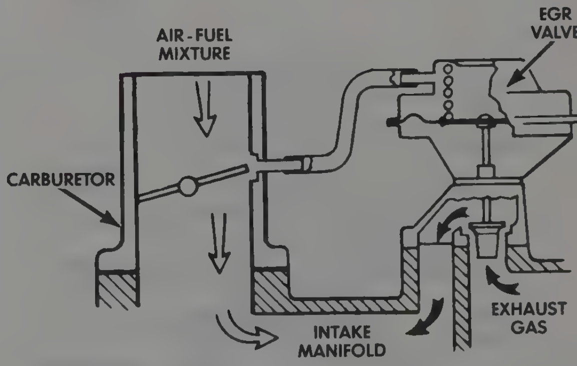

AIR-FUEL MIXTURE
EGR VALVE
CARBURETOR
EXHAUST GAS
INTAKE MANIFOLD

Figure 20-8. Exhaust gas is recirculated into the intake manifold to reduce oxides of nitrogen. (Courtesy of Chevrolet Motor Division, General Motors Corporation)

EGR Valve. A vacuum-actuated, poppet-type valve called the *exhaust gas recirculation (EGR) valve,* is used to control the amount of exhaust gas flowing from the exhaust gas crossover to the intake manifold. The EGR valve passes small amounts of exhaust gas into the intake manifold below the carburetor. Very little NO_x is formed at idle or at light engine loads, but formation increases rapidly during acceleration. Therefore, the EGR valve is closed at idle, and as the throttle opens, the EGR valve opens, recirculating exhaust gases to reduce NO_x.

A typical EGR valve (Figure 20-9) contains an *acutating diaphragm* and *spring* connected to a *valve* by a *shaft*. The actuating diaphragm is spring-loaded to keep the valve, which is housed in the *valve chamber*, closed in the absence of vacuum. As the throttle valves open and engine speed increases, vacuum is applied to the diaphragm in the EGR valve. This vacuum signal comes from an EGR port on the carburetor. The vacuum pulls the diaphragm up, opening the EGR valve. Variations in the vacuum signal control the amount of exhaust gas that is recirculated. A *seal* around the shaft prevents exhaust gases from the valve chamber from entering the actuating diaphragm area.

On most engines, the EGR is blocked when the engine is cold. This improves cold engine response and smoothness. On carbureted engines, a *temperature control valve* (Figure 20-7) is used to block the vacuum signal on a cold engine. On EFI engines, the electronic control unit turns the EGR on and off.

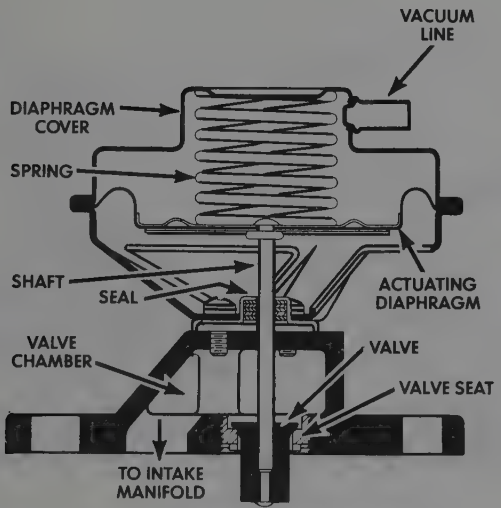


Figure 20-9. Typical EGR valve. (Courtesy of Chevrolet Motor Division, General Motors Corporation)

Ignition Timing Control

Ignition timing plays a critical role in the formation of emissions. To control these pollutants, ignition timing must be precisely controlled and yet maintain good driveability and fuel economy.

As described in Unit 13, when engine speed increases, ignition timing must be advanced so that the spark occurs well before the piston reaches TDC (top dead center). This assures maximum temperature and pressure from the combustion process. However, the fuel charge tends to burn very quickly and incompletely. The result is increased HC and CO emissions. The high temperature and pressure rise of the combustion also contribute to the formation of NO_x.

Limiting ignition advance causes combustion to proceed more slowly and completely, reducing HC and CO emissions. The slower, longer burning allows more of the fuel to burn, and the longer burn time raises the exhaust temperature, allowing burning to continue during and after the exhaust stroke.

Dual pickup or dual point distributors (discussed in Unit 13) may be used to provide the required timing. Dual vacuum advance mechanisms are also used to reduce HC emissions at idle by retarding timing at idle.

Spark Delay Valve. Some ignition systems have a *spark delay valve* (Figure 20-10) to delay spark advance during rapid acceleration from idle or from speeds below 15 MPH. The spark delay valve also cuts off spark advance immediately upon deceleration. It is installed in the vacuum line between the carburetor and the distributor.

The spark delay valve is color-coded to show the amount of built-in restriction for various applications. When a spark delay valve is replaced, the new valve should be color-coded the same as the original. Figure 20-10 shows typical color-coding for spark delay valves.

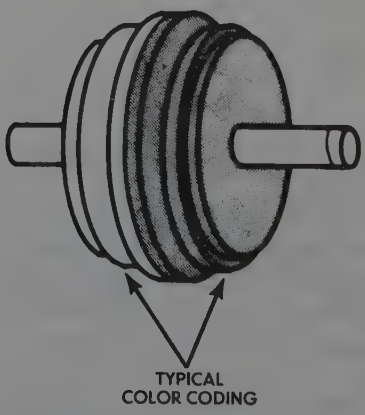


Figure 20-10. Typical spark delay valve.

A cross section of a spark delay valve is shown in Figure 20-11. It has one or more *internal restrictors* and an internal *umbrella check valve.* On mild accelerations, the umbrella check valve remains in the closed position, and the vacuum signal to the distributor load (vacuum) advance mechanism is delayed by the restrictors. After a short delay, the distributor reaches full vacuum advance for normal performance.

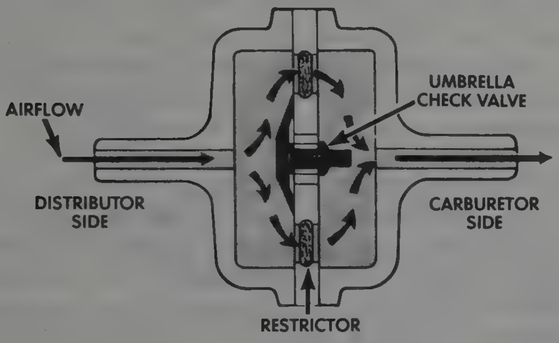

AIRFLOW
UMBRELLA CHECK VALVE
DISTRIBUTOR SIDE
CARBURETOR SIDE
RESTRICTOR

Figure 20-11. Cross section of a spark delay valve.

During all closed-throttle decelerations and all accelerations from about 16 MPH, the umbrella check valve opens and allows an unrestricted vacuum signal to reach the load (vacuum) advance mechanism on the distributor. With an unrestricted advance signal, the load advance setting returns to its normal position for that particular speed and load condition. The umbrella check valve operation allows a rapid reduction of spark advance in order to prevent an over-advance on acceleration from about 16 MPH.

Thermostatic Vacuum Control Valve. On some engine applications a *thermostatic vacuum control valve* (Figure 20-12) is used to reduce the possibility of engine overheating when operating conditions reach extremely high temperatures. This valve is mounted in the coolant passage in the cylinder block, cylinder head, or thermostat housing. When the engine coolant temperature (at idle) reaches a specified maximum value, the *vacuum valve*, controlled by the *thermal sensor*, opens

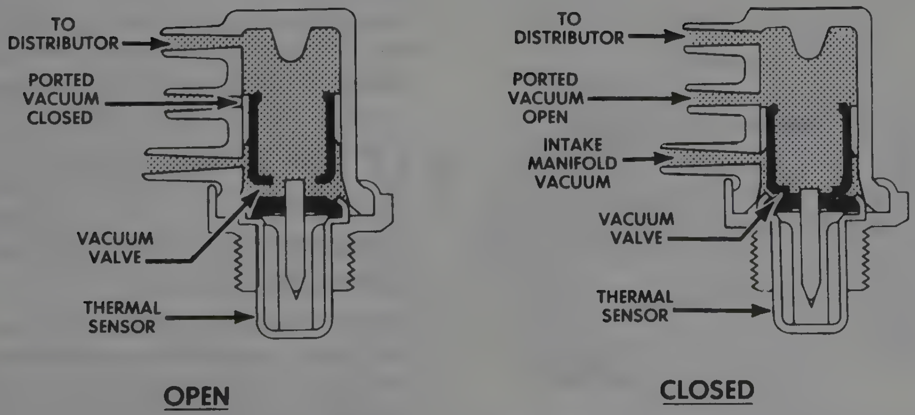

TO DISTRIBUTOR
PORTED VACUUM CLOSED
VACUUM VALVE
THERMAL SENSOR
OPEN
TO DISTRIBUTOR
PORTED VACUUM OPEN
INTAKE MANIFOLD VACUUM
VACUUM VALVE
THERMAL SENSOR
CLOSED

Figure 20-12. A thermostatic vacuum control valve protects against overheating. (Courtesy of Chrysler Corporation)

automatically and applies intake manifold vacuum directly to the vacuum advance mechanism of the distributor. This increases engine idle speed and provides additional engine cooling. When the engine has cooled to a normal operating temperature, the vacuum valve closes.

Ported vacuum is engine vacuum above the carburetor throttle plate (valve). Ported vacuum to the distributor exists only when the carburetor throttle plate (valve) is opened and the thermostatic vacuum control valve is closed. Most load advance systems use ported vacuum.

A thermostatic vacuum control valve is also used on the vacuum line to some EGR valves. When the engine begins to overheat, the vacuum signal to the EGR valve is turned on or off (depending on the type of EGR system) to stop EGR function until engine is cool.

Vacuum Advance System Controlled by Manual Transmission. Since emissions are heaviest during acceleration, and since spark advance contributes to emissions, a method is needed to shut off vacuum advance during periods of heaviest engine load — such as acceleration in first, second, and third gears. On the other hand, little accelerating is done in fourth gear, yet the car is most often operated at partial throttle in this gear. Consequently, vacuum advance is required in fourth gear. The timing control required by these conditions is achieved with a vacuum advance system controlled by manual transmission (Figure 20-13).

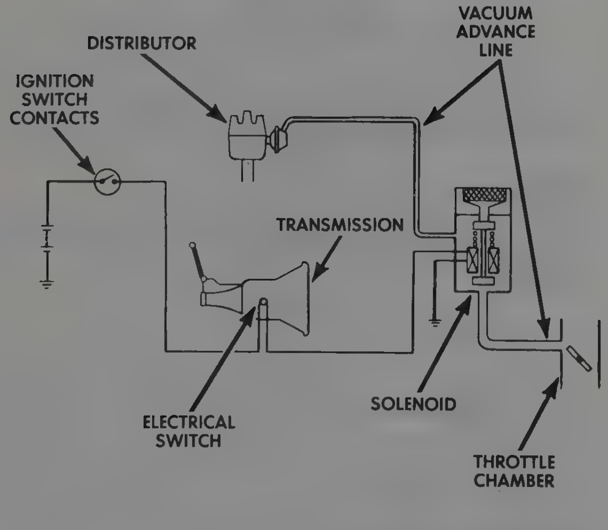


Figure 20-13. Typical vacuum advance system controlled by manual transmission. (Courtesy of Nissan Motor Corporation in U.S.A.)

This system incorporates an *electrical switch* and a *solenoid* to control vacuum to the distributor. The electrical switch is mounted on the transmission. When the shift lever is in any position except fourth or fifth gear, the solenoid is energized, and vacuum from the carburetor port bleeds off to the air cleaner, preventing vacuum advance. When the shift lever is in fourth or fifth gear, the electrical switch is turned off, and the solenoid is de-energized. This allows the ported vacuum to reach the distributor, and the timing is advanced.

On-board Computers. Most late-model vehicles have an on-board computer used to control the fuel injection or carburetor feedback system. This computer, or a separate computer, is increasingly being used to control ignition timing. A computer-controlled timing system can make very precise timing adjustments for maximum power, high mileage, and lower emissions. A wiring diagram for one manufacturer's computer-controlled timing system is shown in Figure 20-14.

On-board computers allow a lean air-fuel mixture to be ignited according to different modes of engine operation by delivering an infinite number of advance curves. The computer uses an electronic printed circuit board which simultaneously receives signals from all the sensors and within milliseconds computes them to determine how the engine is operating. The ignition timing is then advanced or retarded.

The computer determines the exact instant when ignition is required. It then signals the ignition coil to produce the electrical impulses that fire the spark plugs. This advancing and retarding of the ignition timing is not based on a constant curve. The curves are infinitely variable.

Carburetor Emission Control Equipment

Over the years, carburetors have undergone changes to provide better control over the air-fuel mixture. Each carburetor system has been studied for ways to lower emissions and increase fuel mileage. In addition, a number of emission-related components have been added.

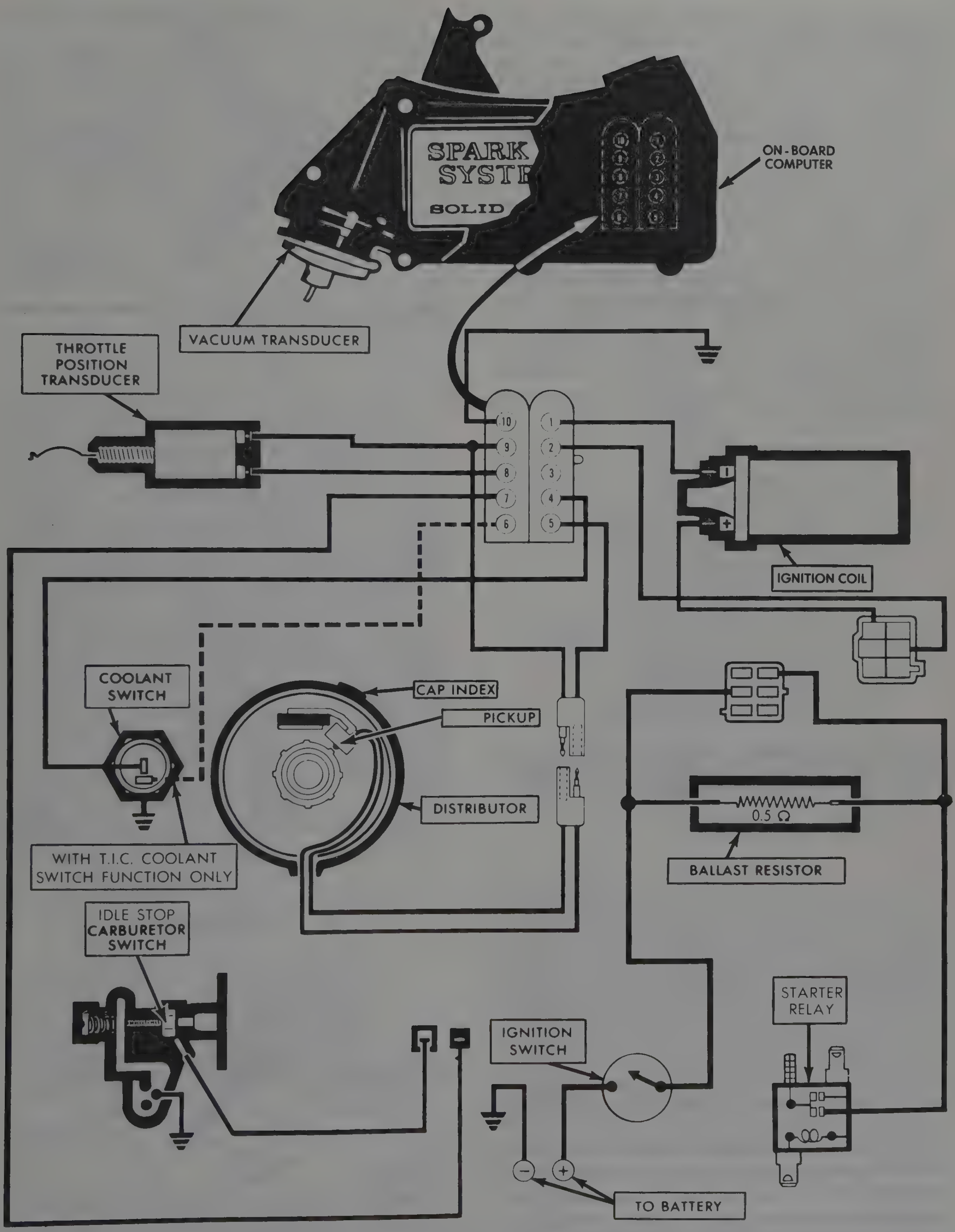

SPARK
SYST
SOLID
ON-BOARD COMPUTER
VACUUM TRANSDUCER
THROTTLE POSITION TRANSDUCER
10
9
8
7
6
1
2
3
4
5
IGNITION COIL
COOLANT SWITCH
CAP INDEX
PICKUP
DISTRIBUTOR
WITH T.I.C. COOLANT SWITCH FUNCTION ONLY
0.5 Ω
BALLAST RESISTOR
IDLE STOP CARBURETOR SWITCH
IGNITION SWITCH
STARTER RELAY
TO BATTERY

Figure 20-14. Typical wiring diagram for computer-controlled electronic spark timing system. (Courtesy of Chrysler Corporation)

Dashpot. An accelerator "shock absorber," the *dashpot* (Figure 20-15) controls the rate at which the throttle plates close when the accelerator pedal is released. The dashpot is mounted on the carburetor and attached to the *throttle linkage*. It was originally developed to control carburetion upon deceleration as an aid to the smooth operation of automatic transmissions. It still performs this function, but it is also an important factor in controlling exhaust emissions upon deceleration. Since the throttle plate is held open longer, more air can enter the manifold to help prevent fuel from collecting on the inner surfaces of the manifold. This helps prevent flash vaporization. Also, the additional air leans out the air-fuel mixture and thus makes it more completely combustible.

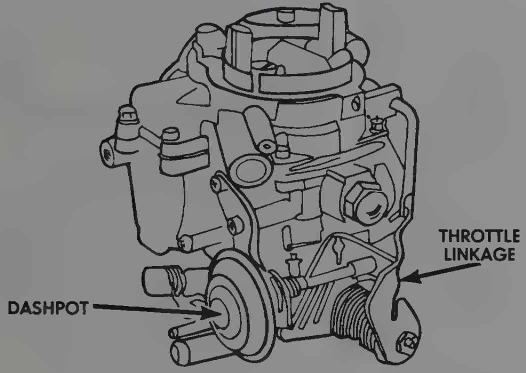


Figure 20-15. The dashpot controls the rate at which the throttle plates close. (Courtesy of Chevrolet Motor Division, General Motors Corporation)

A cross section of a typical dashpot is shown in Figure 20-16. A *spring* and *plunger* are attached to a *diaphragm* in an *air chamber*. The spring pushes the plunger outward as the throttle plate is opened. When the throttle plate closes, the throttle linkage exerts pressure on the dashpot plunger, which pushes on the diaphragm, causing the air in the dashpot chamber to leak out slowly. This allows the throttle plate to slowly return to the idle position.

Throttle Solenoid Positioner. A condition in which the engine runs after the ignition switch is turned off is called *run-on* or *dieseling*. The problem is caused by deposits in the combustion chamber that are hot enough to cause ignition of the air-fuel mixture in the combustion chamber. One method of preventing dieseling is to shut the throttle plates tightly when the engine is turned off. This prevents enough air from entering the cylinders to allow dieseling.

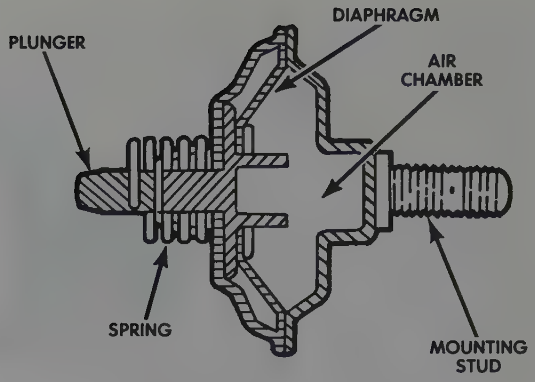


Figure 20-16. Cross section of a typical dashpot. (Courtesy of Ford Motor Company)

Most late-model carburetors are equipped with a *throttle solenoid positioner* (Figure 20-17). A *plunger* on the *solenoid* contacts the *idle speed screw* on the carburetor *throttle lever*. The plunger extends when electrical power is on and retracts when the power is turned off. The throttle solenoid positioner is used as an anti-dieseling device when the ignition switch is off. When the ignition switch is turned off, the plunger retracts and allows the throttle lever to fully close the carburetor throttle plate. Since the throttle plate is fully closed, the engine cannot get enough air and fuel to run-on. The throttle solenoid positioner is also used to increase the throttle opening when the vehicle air conditioning is turned on.

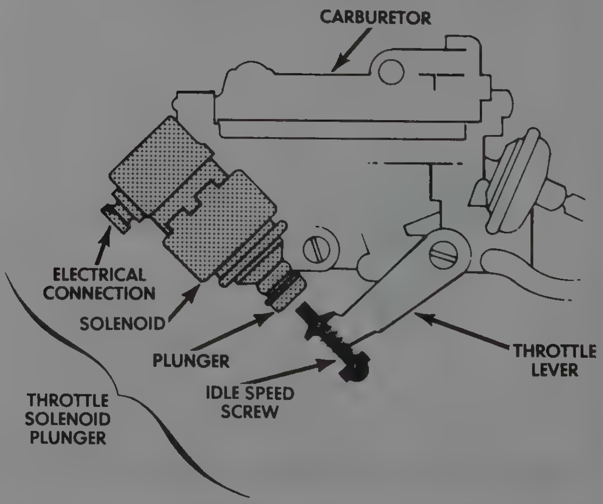


Figure 20-17. Throttle solenoid positioner. (Courtesy of Chrysler Corporation)

Heated Intake Air System

Heating the air entering the engine allows the carburetor to be calibrated much leaner to reduce HC emissions, improve engine warm-up characteristics, and minimize carburetor icing during warm-up operation. This is accomplished by using a heated intake air system (Figure 20-18). It incorporates an air cleaner with a *temperature sensor, air bleed valve*, a *vacuum motor*, a *damper assembly*, and connecting *vacuum hoses*. The vacuum motor, controlled by the temperature sensor that opens or closes the air bleed valve, operates the damper assembly to control the airflow. This provides either preheated air from a shroud around the exhaust manifold or unheated under-the-hood air.

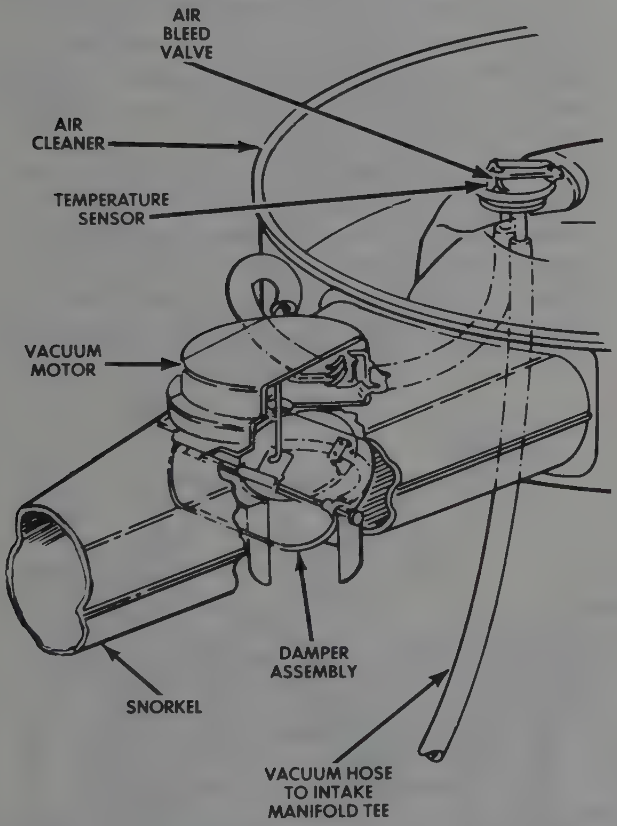
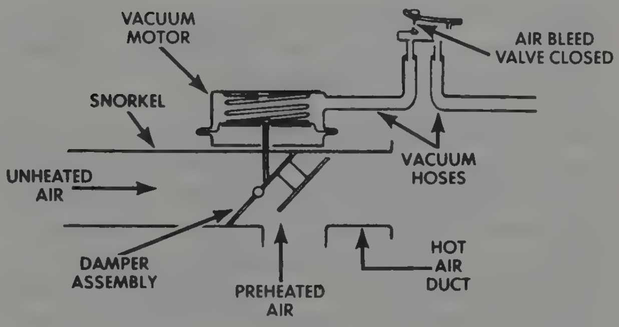
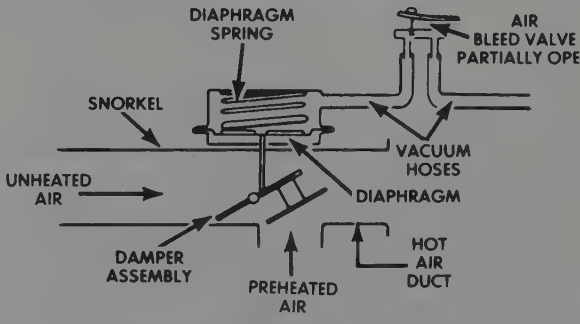

AIR BLEED VALVE
AIR CLEANER
TEMPERATURE SENSOR
VACUUM MOTOR
DAMPER ASSEMBLY
SNORKEL
VACUUM HOSE TO INTAKE MANIFOLD TEE

Figure 20-18. Typical heated intake air system. (Courtesy of Cadillac Motor Car Division, General Motors Corporation)

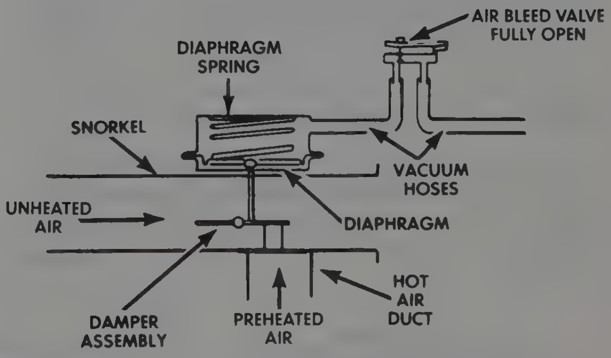
The thermostatically controlled air cleaner has three modes of operation: *hot air delivery mode, regulating mode,* and *cold air delivery mode* (Figure 20-19).


VACUUM MOTOR
AIR BLEED VALVE CLOSED
SNORKEL
VACUUM HOSES
UNHEATED AIR
DAMPER ASSEMBLY
PREHEATED AIR
HOT AIR DUCT

HOT AIR DELIVERY MODE


DIAPHRAGM SPRING
AIR BLEED VALVE PARTIALLY OPEN
SNORKEL
VACUUM HOSES
DIAPHRAGM
UNHEATED AIR
DAMPER ASSEMBLY
PREHEATED AIR
HOT AIR DUCT

REGULATING MODE


AIR BLEED VALVE FULLY OPEN
DIAPHRAGM SPRING
SNORKEL
VACUUM HOSES
UNHEATED AIR
DIAPHRAGM
HOT AIR DUCT
DAMPER ASSEMBLY
PREHEATED AIR

COLD AIR DELIVERY MODE

Figure 20-19. Thermostatically controlled air cleaner operating modes. (Courtesy of Cadillac Motor Car Division, General Motors Corporation)

Hot Air Delivery Mode. When the temperature of the air entering the air cleaner is 85° F or lower, the *air bleed valve* is fully closed, directing engine vacuum to the *vacuum motor*, which in turn closes the *damper assembly* to *outside* or *unheated air*. With the damper assembly closed, the cool under-the-hood air flows between the exhaust manifold and a shroud surrounding the manifold, where it is heated. *Preheated air* then flows up through the hot air duct to the air cleaner and into the engine.

Regulating Mode. As the temperature inside the air cleaner rises to between 85° F and 105° F, the *air bleed valve* begins to open and bleed off vacuum from the *vacuum motor.* This allows the vacuum motor's *diaphragm spring* to partially open the damper assembly, allowing some *unheated air* to mix with the *preheated air* and keep the air temperature from becoming too high.

Cold Air Delivery Mode. When the temperature in the air cleaner rises above 130° F, the *air bleed valve* opens wide, reducing the vacuum until it will no longer hold the *damper assembly* closed to unheated air. *Diaphragm spring* pressure then opens the damper assembly completely, allowing only cooler air (unheated air) to enter the carburetor. Under full throttle conditions, the vacuum is not strong enough to hold the damper assembly closed. Diaphragm spring pressure then opens the damper assembly, allowing passage of cooler air (unheated air). Also, when the engine is off and no vacuum exists, the damper assembly is opened, blocking the hot air duct.

Air Injection Systems

The purpose of an **air injection system** is to provide the air needed to burn the hydrocarbons remaining in the exhaust gas as it leaves the combustion chamber. *Fuel, heat,* and *oxygen* are all necessary for burning, or combustion.

The *fuel*, or unburned hydrocarbons in the exhaust gas, and the *heat* of these gases satisfy two of the essential requirements for combustion. *Oxygen*, the third requirement, is contained in the air supplied at the engine *exhaust ports* by the *air nozzles* (Figure 20-20).

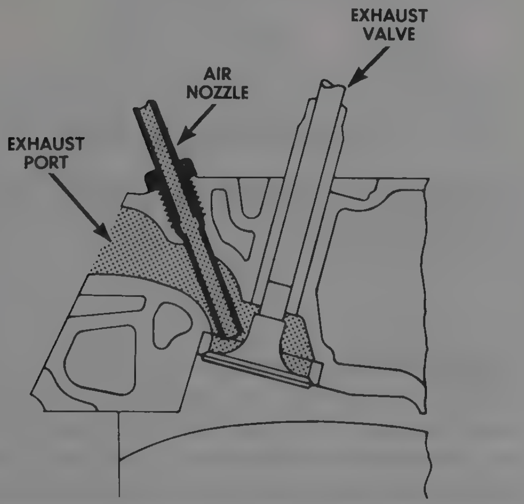


Figure 20-20. Air injected into the exhaust port helps to burn the unburned hydrocarbons as they leave the combustion chamber. (Courtesy of Chrysler Corporation)

Air Pump Air Injection System. The basic parts of an air pump air injection system are shown in Figure 20-21. Air is drawn into an *air pump*, where it is compressed and fed through the *diverter valve*, through the *check valve* via a *hose*, through a *pipe assembly*, and then through an *air nozzle* into the exhaust port past the *exhaust valve*.

The diverter valve is used to bypass the air injection system during deceleration. During engine deceleration, the exhaust gases in the exhaust valve area are overly rich with fuel vapors. Under this condition, a backfire would result as soon as the fresh air from the air pump mixed with the overly rich vapor.

The diverter valve is triggered by sharp rises in vacuum. The vacuum signal is taken from just beneath the *throttle plate* (Figure 20-21). When a sharp rise in vacuum is sensed, as during engine overrun, the diverter valve exhausts the air pump output into the atmosphere

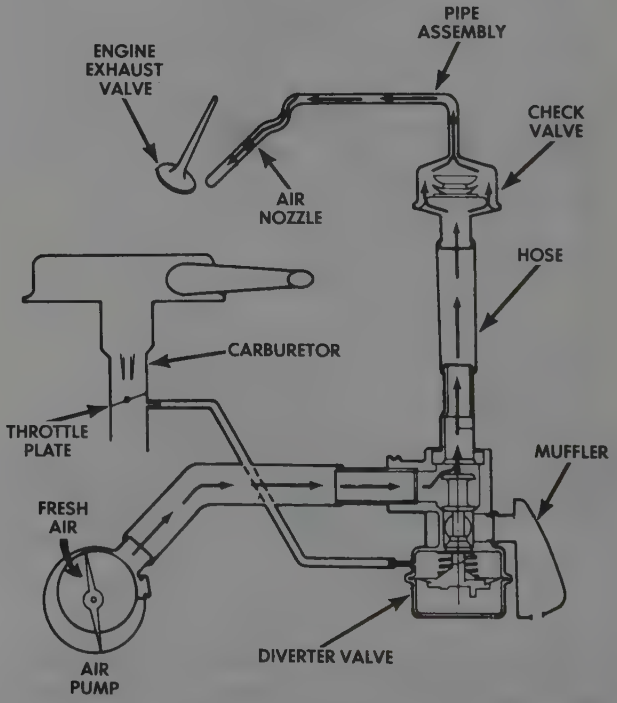


Figure 20-21. Basic parts of an air pump air injection system. (Courtesy of Chevrolet Motor Division, General Motors Corporation)

for a few seconds. Since the compressed air from the air pump never reaches the manifolds, no backfire occurs.

Check Valve. A one-way valve, the check valve, prevents exhaust gas from entering and damaging the air pump. If for any reason (such as drive-belt failure) the pump becomes inoperative, the check valve will not allow exhaust gas into the air pump. Under normal operating conditions, air pressure from the air pump is sufficient to prevent exhaust gas from entering the pump.

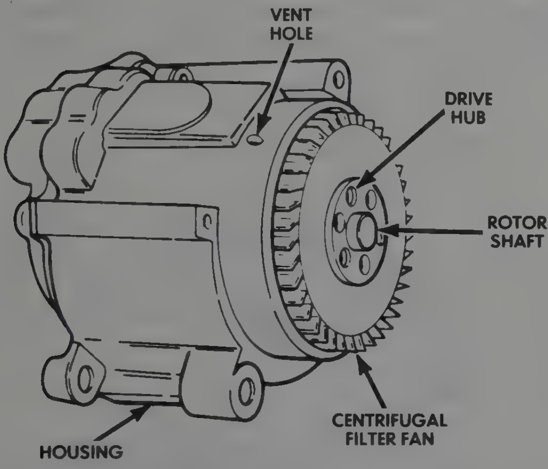

VENT HOLE
DRIVE HUB
ROTOR SHAFT
CENTRIFUGAL FILTER FAN
HOUSING

Figure 20-22. Exterior parts of a typical air pump. (Courtesy of Chrysler Corporation)

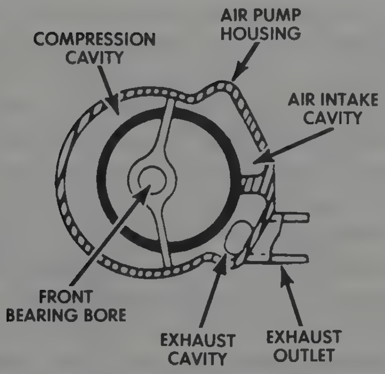

COMPRESSION CAVITY
AIR PUMP HOUSING
AIR INTAKE CAVITY
FRONT BEARING BORE
EXHAUST CAVITY
EXHAUST OUTLET

Figure 20-23. Cross section of an air pump housing. (Courtesy of Chevrolet Motor Division, General Motors Corporation)

Air Pump. On this air injection system the air pump is a vane-type pump driven by a V-belt from the crankshaft. The major operating components of the air pump are enclosed in a die-cast aluminum *housing* (Figure 20-22). A *centrifugal filter fan, rotor shaft,* and *drive hub* are visible on the pump exterior. The aluminum pump housing (Figure 20-23) has cavities for *air intake, compression, exhaust,* and a *front bearing bore.* The front bearing supports the rotor shaft. The rotor, driven by the rotor shaft, positions and drives the two vanes.

The vanes (*leading* and *trailing*) are located 180° apart (Figure 20-24) and rotate around

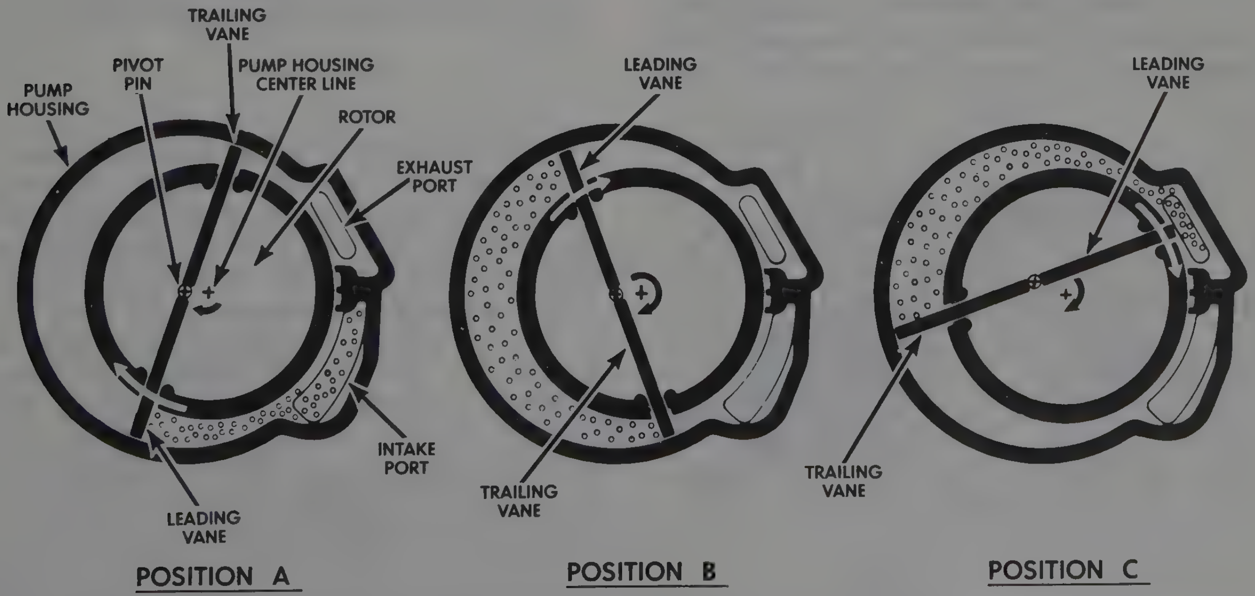

TRAILING VANE
PIVOT PIN
PUMP HOUSING CENTER LINE
PUMP HOUSING
ROTOR
EXHAUST PORT
INTAKE PORT
LEADING VANE
POSITION A
LEADING VANE
TRAILING VANE
POSITION B
LEADING VANE
TRAILING VANE
POSITION C

Figure 20-24. Operation of the vane-type air pump. (Courtesy of Chevrolet Motor Division, General Motors Corporation)

the *pivot pin*, which is located on the centerline of the pump housing. The *rotor* that drives the vanes rotates off the centerline of the pump housing. This creates changes in the distance between the outside of the rotor and the inner wall of the air pump housing during rotor rotation. As the leading vane moves past the *intake port* (position A on Figure 20-24), it is moving from a small area to a large area. This creates a partial vacuum and forces air into the pump. As the vanes and rotor continue to rotate, the trailing vane passes the intake port and traps the air between the vanes (position B). The vanes and rotor move the trapped air into a smaller area and compression begins. Compression continues until the leading vane passes the *exhaust port* (position C). There the compressed air passes out of the air pump and to the diverter valve.

Diverter Valve. To prevent backfire, the diverter valve is designed to direct or divert the air from the air pump to the atmosphere. A sudden rise in intake manifold vacuum during deceleration periods creates a vacuum condition under the *diaphragm* of the *valve assembly* shown in Figure 20-25. It is strong enough to pull the valve assembly downward against the *return spring* tension and cause the air from the air pump to be momentarily diverted to the atmosphere through the diverter valve *silencer chamber* or through a separate muffler, depending on type of system.

Air diversion is only momentary, because the orifice hole in the diaphragm soon equalizes pressure on both sides of the diaphragm. The return spring brings the valve assembly back into the normal operating position in a few seconds. A *pressure relief valve* controls pressure within the air injection system by diverting excessive air pump output at higher engine speeds to the atmosphere through the silencer chamber.

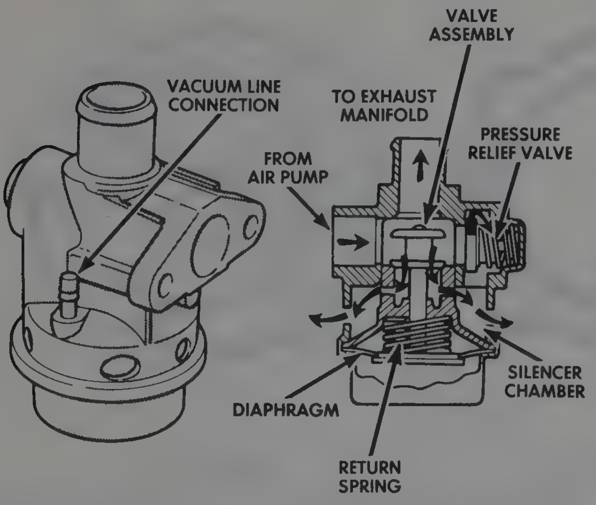


Figure 20-25. Operation of a diverter valve. (Courtesy of Chrysler Corporation)

Aspirator Valve Air Injection System. One disadvantage of the air injection system is that the air pump requires engine power to operate it. Some air injection systems use an *aspirator* or *pulsing valve* (Figure 20-26) to pump air instead of an engine-driven air pump. They are called *aspirator valve air injection systems*.

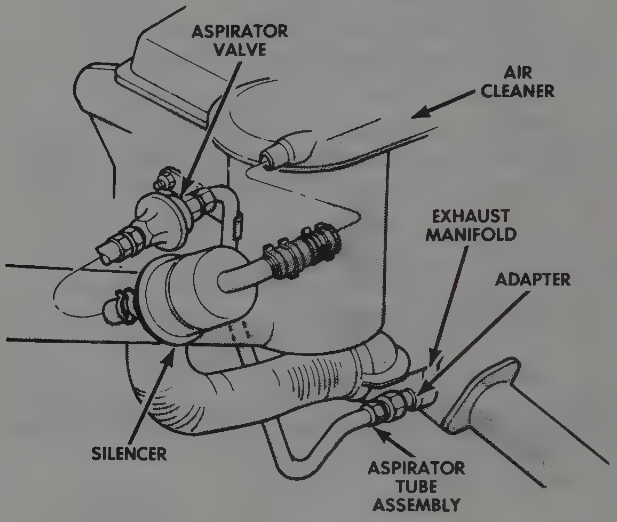


Figure 20-26. Typical aspirator valve air injection system. (Courtesy of Chrysler Corporation)

An aspirator valve uses exhaust pressure pulsation to draw air into the exhaust system, reducing CO and HC emissions. It draws fresh air from the clean side of the air cleaner past a one-way, *spring-loaded diaphragm* (Figure 20-27) made of high-temperature rubber.

The spring-loaded diaphragm opens to allow fresh air to mix with the exhaust gas during negative (–) pressure (vacuum) pulses that occur in the exhaust ports and manifold passages (View A in Figure 20-27). If the pressure is positive (+) (lack of vacuum), the spring-loaded diaphragm closes (View B), and no exhaust gas is allowed to flow into the clean side of the air cleaner. The aspirator valve works most efficiently at idle and at slightly off-idle, where the negative (–) pulses are maximum.

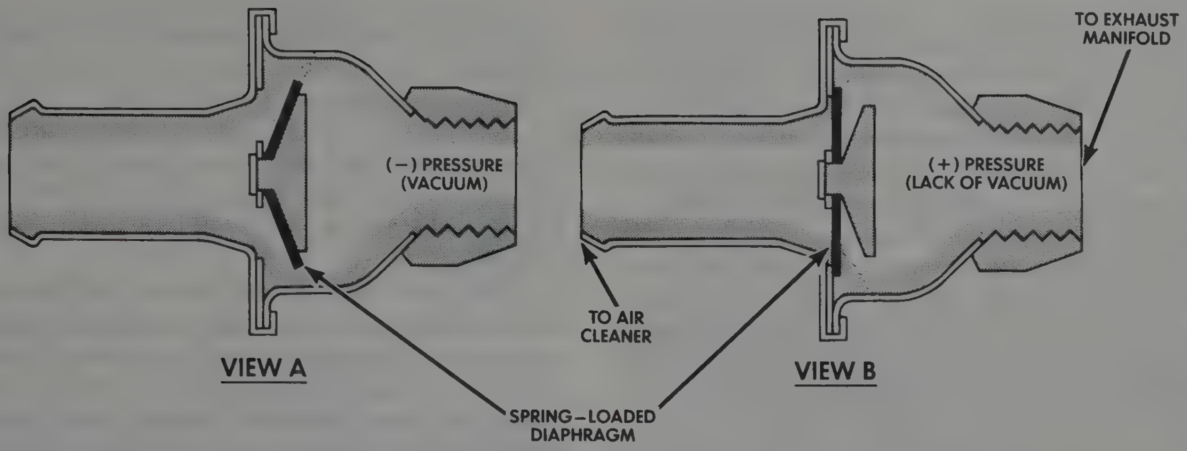

TO EXHAUST MANIFOLD
(−) PRESSURE (VACUUM)
(+) PRESSURE (LACK OF VACUUM)
TO AIR CLEANER
VIEW A
VIEW B
SPRING–LOADED DIAPHRAGM

Figure 20-27. Operation of the aspirator or pulsing valve. (Courtesy of Chrysler Corporation)

At higher engine speeds, the aspirator valve remains closed. A *silencer* (refer to Figure 20-26) is connected between the aspirator and the air cleaner.

Catalytic Converter

A substance or agent which promotes a chemical reaction without becoming part of the reaction is a **catalyst.** A **catalytic converter**, mounted in the exhaust system (Figure 20-28) promotes oxidation, or burning of exhaust emissions, but the catalyst itself is unaffected.

Construction. The catalytic material (catalyst) used in most catalytic converters is *platinum*. Providing there is enough oxygen in the exhaust gas leaving the engine, the catalytic converter changes the hydrocarbons (HC) and carbon monoxide (CO) into harmless water (H_2O) vapor and carbon dioxide (CO_2). These catalytic converters are referred to as two-way converters. Most late-model vehicles have a three-way catalytic converter that also controls oxides of nitrogen (NO_x). Its catalytic agents are *platinum* and *rhodium*, which convert NO_x into free oxygen and nitrogen and also convert HC and CO into harmless compounds.

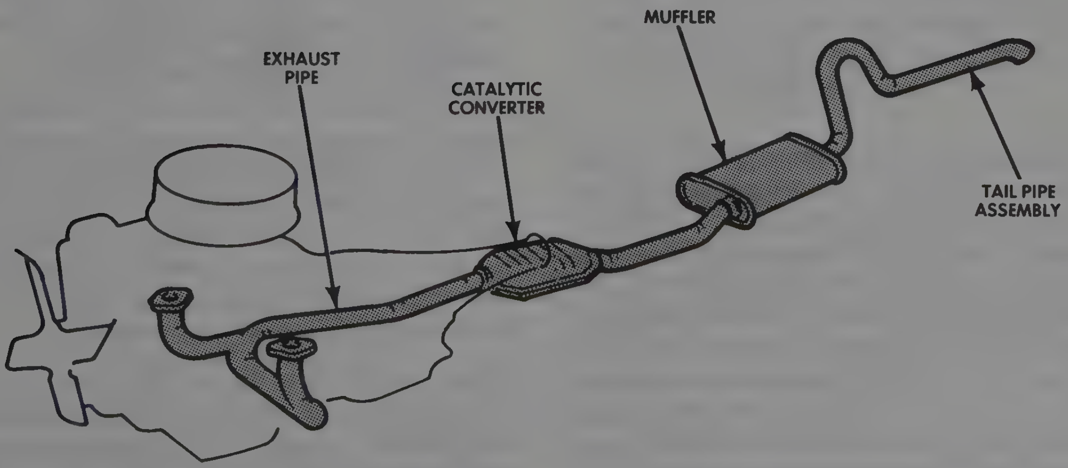

MUFFLER
EXHAUST PIPE
CATALYTIC CONVERTER
TAIL PIPE ASSEMBLY

Figure 20-28. The catalytic converter is mounted in the exhaust system. (Courtesy of Chrysler Corporation)

A typical catalytic converter (Figure 20-29) consists of a *stainless steel shell* containing one or two ceramic *cores*, or *elements*, and a *flow diffuser*. The flow diffuser deflects or diffuses exhaust gas over the core. These cores are coated with the catalytic agent and wrapped with a *stainless steel mesh blanket* to protect it against road shock, vibrations, and rapid changes in temperature. The ceramic cores have thousands of small honeycomb passages. This unique core construction and the porous nature of the ceramic results in an inner surface area that is about the same size as the flight deck of a modern aircraft carrier. The extremely large surface area is needed to ensure that the unburned emissions will come in contact with the catalytic coating (catalyst) on the thousands of core passages.

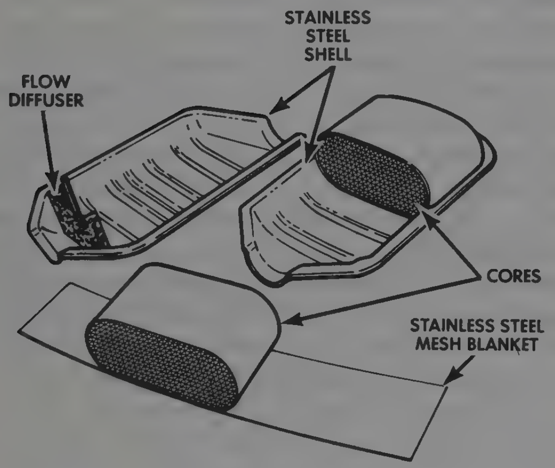


Figure 20-29. Typical catalytic converter construction. (Courtesy of Chrysler Corporation)

Operation. As the catalytic reaction takes place, normal internal temperatures of the catalytic converter rise to about 1,500° F, while normal outer surface temperatures generally reach about 1,000° F. However, if the engine is in poor operating condition, operating under a severe load, in need of a tune-up, or has several misfiring cylinders, higher temperatures than normal are easily reached (both inside and outside the converter shell). Excessively high temperatures reduce the life of the catalytic converter and can destroy the cores.

If a catalytic converter receives exhaust gas rich with fuel (because of poor engine operating condition), it can become a catalytic furnace. When spark plugs are not firing, raw fuel (excess HC) is delivered to the catalytic converter. When misfiring occurs, heat in the catalytic converter can skyrocket, and this abnormally high heat can quickly destroy the converter.

CAUTION: Diagnostic tests that require spark plug cable removal or shorted spark plugs should be minimized to prevent severe catalytic converter overheating. Never turn the key switch off when driving at road or highway speeds in order to diagnose a particular problem. This practice can cause severe catalyst overheating. Also, minimize idle time when working on the engine. Idle is the worst running condition for a catalytic converter. More heat is developed when the engine is idling for long periods than when cruising at normal highway speeds.

Some emission systems use air from the air injection system to help the catalytic converter work. Air is directed from the air pump or aspirator valve into the catalytic converter. The extra air helps complete the combustion of the exhaust gas. During warm-up, or when there is an overly rich air-fuel mixture, the air is switched upstream (as described earlier in this unit under the heading of "Air Injection System") to the exhaust manifold to burn the exhaust gas before it reaches the catalytic converter.

Feedback Systems

The purpose of a **feedback system** (or closed-loop system) is to sense the engine air-fuel ratio and correct it to the ideal (stoichometric) air-fuel ratio of 15:1.

EFI Feedback Systems. An exhaust *oxygen sensor*, located in the exhaust manifold, produces a variable voltage in relation to the oxygen content in the exhaust system (Figure 20-30). This voltage signal is used by the *electronic control unit* to adjust the pulse time of the fuel injectors (See Unit 17 for a detailed discussion of the oxygen sensor).

Carburetion Feedback Systems. It is also possible to use a feedback system with a carburetion system. This type of system has the same basic components as the EFI feedback system. A carburetor with a *mixture con-*

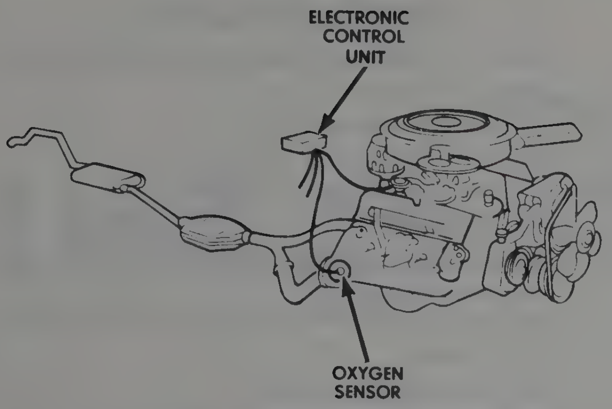


Figure 20-30. Typical location of feedback system components used in an EFI system. (Courtesy of Cadillac Motor Car Division, General Motors Corporation)

trol solenoid is shown in Figure 20-31. The solenoid controls a *metering rod*, and the position of the metering rod is determined by the electronic control unit.

Some feedback carburetors use a computer-controlled solenoid to control the amount of fuel delivered. Others use the solenoid to control the amount of air in the carburetor air bleed system. Some use the solenoid to control both air and fuel.

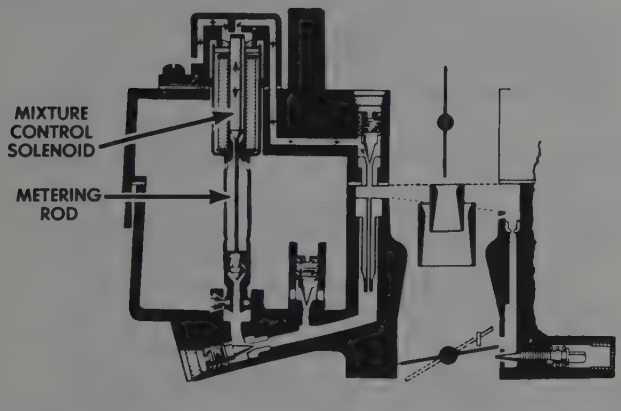


Figure 20-31. A carburetion feedback system uses an electrically controlled carburetor. (Courtesy of Cadillac Motor Car Division, General Motors Corporation)

KEY TERMS

Air injection system: A system that provides the air needed to burn the hydrocarbons (HC) in the exhaust gas as it leaves the combustion chamber.

Carbon monoxide: An emission that is the result of incomplete combustion of fuel due to an insufficient amount of oxygen in the air-fuel mixture. It is abbreviated CO.

Catalyst: A substance that promotes a chemical reaction without itself becoming part of the chemical reaction.

Catalytic converter: A device that promotes oxidation (burning) of exhaust emissions and is mounted in the exhaust system.

Evaporation control system: A system designed to prevent gasoline vapors (HC) from escaping into the atmosphere from the fuel tank and carburetor.

Exhaust gas recirculation system: A system used to reduce oxides of nitrogen (NO_x).

Feedback system: A system that senses the engine air-fuel ratio and corrects it to the ideal air-fuel ratio.

Heated intake air system: A system that heats the air entering the engine to reduce HC emissions, improve engine warm-up characteristics, and minimize carburetor icing.

Hydrocarbons: A polluting emission that is the result of incomplete combustion or the result of vapors escaping from the crankcase or fuel system. Hydrocarbons are unburned or partially burned fuel (gasoline). They are abbreviated HC.

Oxides of nitrogen: An emission produced by most forms of combustion, especially at high temperatures. When combined with unburned hydrocarbons (HC) and acted upon by sunlight, they form smog. They are abbreviated NO_x.

Positive crankcase ventilation (PCV) system: A system used to remove harmful corrosive gas from the crankcase.

SELF-CHECK

1. Describe the four major automotive emissions that cause pollution.
2. What engine operating conditions create the most emissions?
3. What kind of emissions are created when the engine misfires?
4. How are crankcase emissions controlled?
5. What is the purpose of the PCV valve?

6. How are evaporative emissions controlled?
7. What is the purpose of the vapor canister?
8. How does exhaust gas recirculation reduce the amount of NO_x?
9. What is the purpose of the EGR valve?
10. How does retarded timing help limit emissions?
11. What carburetor equipment is used to lower emissions?
12. How does heated intake air reduce emissions?
13. What is the purpose of an air injection system?
14. What is the purpose of a catalytic converter?
15. What engine operating conditions can cause a catalytic converter to overheat?

DISCUSSION TOPICS AND ACTIVITIES

1. Connect and disconnect selected emission control devices on an engine while observing an infrared exhaust analyzer. What are the results?
2. Connect and disconnect selected emission control devices while observing engine horsepower on a dynamometer. What are the results?

CERTIFICATION PRACTICE

1. The hotter the combustion process, the higher is the level of:
   A. Hydrocarbons (HC)
   B. Carbon monoxide (CO)
   C. Oxides of nitrogen (NO_x))
   D. Particulates
2. Emissions are highest at:
   A. Deceleration
   B. Idle
   C. Cruising
   D. None of the above
3. Oxides of nitrogen (NO_x) are most likely to form during:
   A. Deceleration
   B. Acceleration
   C. Idle
   D. None of the above
4. Catalytic converters are used to control:
   A. Hydrocarbons (HC)
   B. Carbon monoxide (CO)
   C. Oxides of nitrogen (NO_x)
   D. All of the above
5. A feedback system can be used with:
   A. EFI systems
   B. Carburetion systems
   C. Both A and B
   D. Neither A nor B

ANSWERS
1: C, 2: A, 3: B, 4: D, 5: C

Unit 21

TROUBLESHOOTING THE EMISSION CONTROL SYSTEM

Troubleshooting the emission control system is an important part of an engine tune-up. Many engine performance problems such as difficult starting, stalling, rough idle, poor fuel mileage, spark knock (abnormal combustion that results in a pinging noise), and dieseling (engine run-on) can be caused by a malfunction of the emission control system. Since many of these problems can also be caused by a malfunction of the ignition system or the fuel system, the tune-up technician must be able to troubleshoot problems in all three systems.

DEVELOPING JOB COMPETENCIES

When you finish reading and studying this unit, you should be able to:

- Use an exhaust analyzer to measure hydrocarbons (HC) and carbon monoxide (CO).
- Troubleshoot a positive crankcase ventilation (PCV) system.
- Troubleshoot an evaporation control system.
- Troubleshoot an EGR (exhaust gas recirculation) system.
- Troubleshoot ignition timing controls.
- Troubleshoot a heated intake air system.
- Troubleshoot the air injection system.
- Troubleshoot a feedback system.

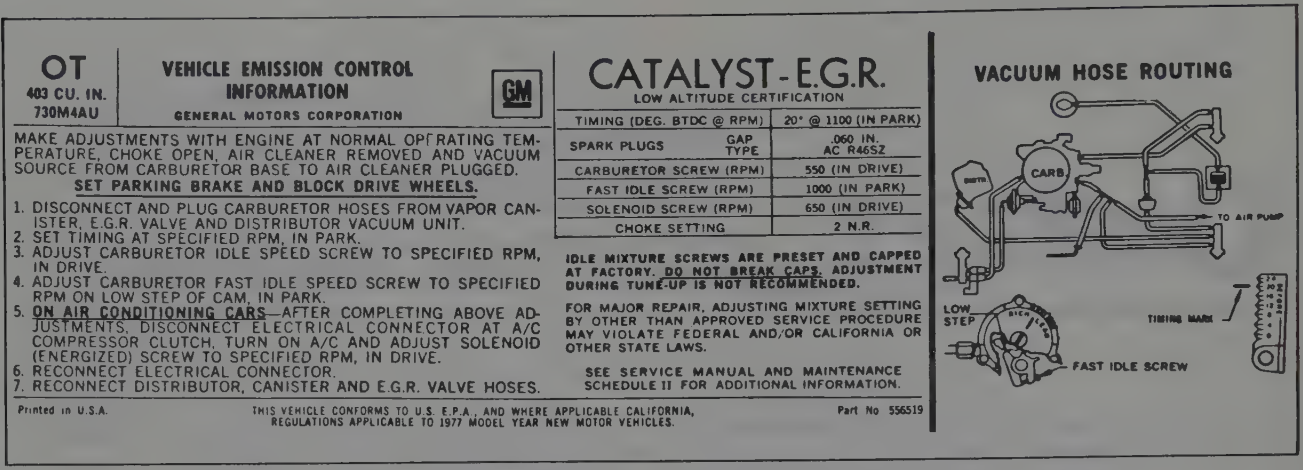
PREPARING TO TROUBLESHOOT THE EMISSION CONTROL SYSTEM

The wide variety of emissions equipment and systems makes it necessary to consult the appropriate service manual for the correct troubleshooting procedures. The type of emission control equipment on the vehicle is identified on the **vehicle emission control information label** (Figure 21-1) located under the hood.

Basic emission control specifications such as curb idle speed, propane-enriched idle speed, ignition timing, and fast idle speed are also included on the vehicle emission control information label. Because types of emission control equipment and emission control specifications vary from one vehicle model to another, the labels also vary. In addition, it is often necessary (as a result of specification or application change occuring during the model year) to change the information on these labels. Each time such a change is made, an updated or revised vehicle emission control information label is prepared.

Correct routing and proper connection of all vacuum hoses are essential to the proper operation of an emission control system. For this reason, a vacuum hose routing diagram is either included on the vehicle emission control label (Figure 21-1) or provided on a separate label under the hood (Figure 21-2). During troubleshooting, always check vacuum lines for leaks and correct connections (if necessary), using this diagram as a guide.

When the type of emission control equipment is identified, a troubleshooting guide or chart (Figure 21-3) should be consulted. Troubleshooting guides or charts are found in most service manuals.



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VEHICLE EMISSION CONTROL INFORMATION
GENERAL MOTORS CORPORATION

GM

MAKE ADJUSTMENTS WITH ENGINE AT NORMAL OPERATING TEMPERATURE, CHOKE OPEN, AIR CLEANER REMOVED AND VACUUM SOURCE FROM CARBURETOR BASE TO AIR CLEANER PLUGGED.

SET PARKING BRAKE AND BLOCK DRIVE WHEELS.

1. DISCONNECT AND PLUG CARBURETOR HOSES FROM VAPOR CANISTER, E.G.R. VALVE AND DISTRIBUTOR VACUUM UNIT.
2. SET TIMING AT SPECIFIED RPM, IN PARK.
3. ADJUST CARBURETOR IDLE SPEED SCREW TO SPECIFIED RPM, IN DRIVE.
4. ADJUST CARBURETOR FAST IDLE SPEED SCREW TO SPECIFIED RPM ON LOW STEP OF CAM, IN PARK.
5. ON AIR CONDITIONING CARS—AFTER COMPLETING ABOVE ADJUSTMENTS, DISCONNECT ELECTRICAL CONNECTOR AT A/C COMPRESSOR CLUTCH, TURN ON A/C AND ADJUST SOLENOID (ENERGIZED) SCREW TO SPECIFIED RPM, IN DRIVE.
6. RECONNECT ELECTRICAL CONNECTOR.
7. RECONNECT DISTRIBUTOR, CANISTER AND E.G.R. VALVE HOSES.

CATALYST-E.G.R.
LOW ALTITUDE CERTIFICATION

TIMING (DEG. BTDC @ RPM)	20° @ 1100 (IN PARK)
SPARK PLUGS GAP TYPE	.060 IN. AC R46SZ
CARBURETOR SCREW (RPM)	550 (IN DRIVE)
FAST IDLE SCREW (RPM)	1000 (IN PARK)
SOLENOID SCREW (RPM)	650 (IN DRIVE)
CHOKE SETTING	2 N.R.

IDLE MIXTURE SCREWS ARE PRESET AND CAPPED AT FACTORY. DO NOT BREAK CAPS. ADJUSTMENT DURING TUNE-UP IS NOT RECOMMENDED.

FOR MAJOR REPAIR, ADJUSTING MIXTURE SETTING BY OTHER THAN APPROVED SERVICE PROCEDURE MAY VIOLATE FEDERAL AND/OR CALIFORNIA OR OTHER STATE LAWS.

SEE SERVICE MANUAL AND MAINTENANCE SCHEDULE II FOR ADDITIONAL INFORMATION.

Printed in U.S.A.

THIS VEHICLE CONFORMS TO U.S. E.P.A., AND WHERE APPLICABLE CALIFORNIA, REGULATIONS APPLICABLE TO 1977 MODEL YEAR NEW MOTOR VEHICLES.

Part No 556519

VACUUM HOSE ROUTING

Figure 21-1. Typical vehicle emission control information label. (Courtesy of Chevrolet Motor Division, General Motors Corporation)

The infrared exhaust analyzer, as mentioned in Unit 4, is one of the basic testing tools used for a tune-up. It is used to sample exhaust gas for fuel system troubleshooting and also provides valuable information on the operation of the emission control system. A typical troubleshooting guide for use with the infrared exhaust analyzer is shown in Figure 21-4.

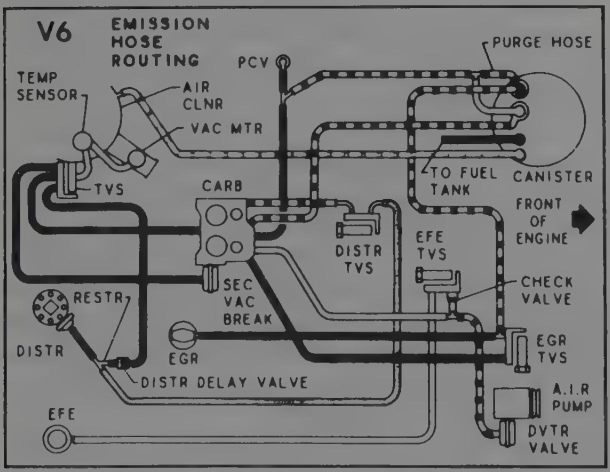

Figure 21-2. Typical emission vacuum hose routing diagram. (Courtesy of Chevrolet Motor Division, General Motors Corporation)

EMISSION CONTROL SYSTEM TROUBLESHOOTING GUIDE

PROBLEM	POSSIBLE CAUSE(S)
HARD START	EGR SYSTEM
STALLS/HESITATES WHEN COLD	EGR SYSTEM, HEATED AIR SYSTEM, VACUUM CONTROL SYSTEM
POOR GAS MILEAGE	EGR SYSTEM, PCV SYSTEM, VACUUM CONTROL SYSTEM
POOR PERFORMANCE	EGR SYSTEM, VACUUM CONTROL SYSTEM
ROUGH IDLE	EGR SYSTEM, PCV SYSTEM, VACUUM CONTROL SYSTEM, IDLE STOP SOLENOID
NOISE	AIR INJECTION SYSTEM
BACKFIRE ON DECELERATION	AIR INJECTION SYSTEM
SPARK KNOCK	EGR SYSTEM, VACUUM CONTROL SYSTEM, TEMPERATURE CONTROLS
RUN-ON AFTER IGNITION IS SWITCHED OFF	IDLE STOP SOLENOID
SMELL OR EXHAUST OVERHEAT	CATALYTIC CONVERTER
HIGH EMISSIONS	ALL SYSTEMS

Figure 21-3. Typical emission control system troubleshooting guide as found in a service manual.

EXHAUST EMISSIONS TROUBLESHOOTING GUIDE

TEST SPEED	READINGS		SYMPTOMS	CAUSES
	CO	HC		
Idle	Normal	High	Rough Idle	1. Low battery. 2. Poor Ignition: a. Condenser. b. Point Ground. c. Plugs, shorted or fouled. d. Plug wires crossed. e. Distributor cap cracked. f. Timing advanced or retarded. 3. Leaky valves. 4. Leaky cylinders.
	Low	High	Rough Idle	Vacuum leak.
	High	High	Rough Idle, Black smoke from tailpipe	1. Restricted air filter. 2. PCV restricted. 3. Carburetion: a. Idle mix too rich. b. Leaking needles and seats. c. Leaky power valve. d. Wrong float setting. e. Faulty choke action.

Figure 21-4. Typical troubleshooting guide used with an infrared exhaust analyzer. (Courtesy of Marquette Products, Automotive Division of Applied Power, Inc.)

TROUBLESHOOTING THE POSITIVE CRANKCASE VENTILATION (PCV) SYSTEM

Poor crankcase ventilation or lack of crankcase ventilation causes rough idle, sludge formation, oil dilution, and air pollution.

CAUTION: Never attempt to compensate for the rough idling conditions by disconnecting the crankcase ventilation system or by making carburetor adjustments. The removal of the components from the engine will adversely affect fuel economy and engine ventilation and thus shorten engine life.

To check the PCV system, first remove the *PCV valve* (Figure 21-5) from the *rocker arm cover* and make sure that it is not plugged. A hissing noise will be heard as air passes by the PCV valve's plunger, and a strong vacuum should be felt when your finger is placed over the PCV valve inlet (Figure 21-5).

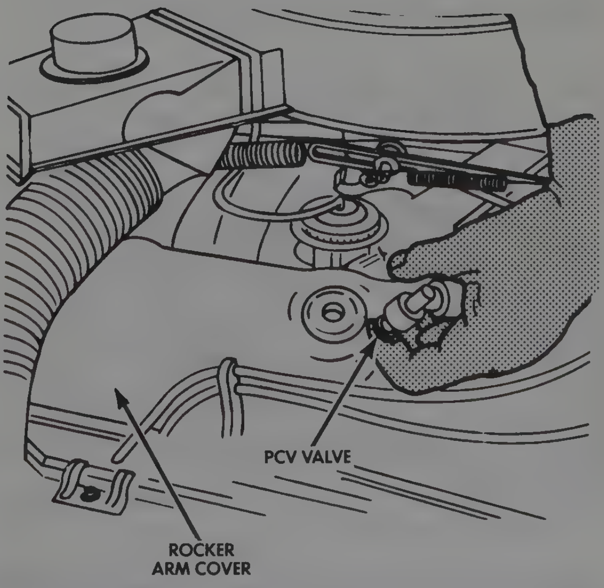

Figure 21-5. Checking the PCV valve for proper operation. (Courtesy of Chrysler Corporation)

Reinstall the PCV valve and then remove the *crankcase inlet air cleaner* (also called oil filler cap). Loosely hold a piece of stiff paper, such as a *parts tag*, over the opening in the *rocker arm cover* (Figure 21-6). After about one minute, the crankcase pressure reduces, and the stiff paper should be sucked against the opening with a noticeable force.

With the engine stopped, remove the PCV valve from the rocker arm cover and shake it (Figure 21-7). A clicking noise should be heard, indicating that the plunger is free. If the PCV system passes all of these tests, it is operating correctly. If not, it requires service.

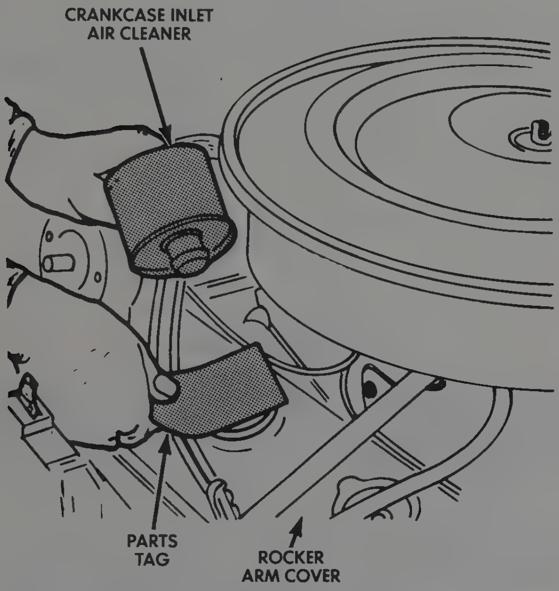

Figure 21-6. Checking for vacuum at the rocker arm cover. (Courtesy of Chrysler Corporation)

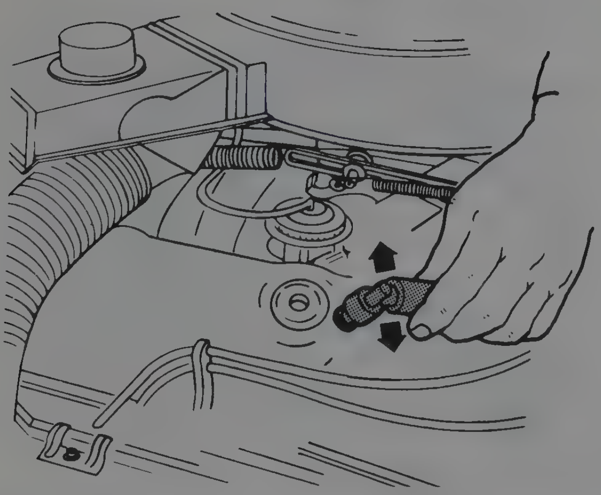

Figure 21-7. The PCV valve should click when it is shaken. If it does not, the plunger is stuck. (Courtesy of Chrysler Corporation)

TROUBLESHOOTING THE EVAPORATION CONTROL SYSTEM

A problem in the evaporation control system generally results in the vehicle owner complaining of gasoline fumes. Check all fuel and vapor lines and hoses for proper connections, and check routing as well as condition. Check the vapor canister vent valve and canister purge valve (if the vehicle is so equipped). Remove the vapor canister to visually check for cracks or damage and replace it if necessary. Replace the filter in the lower section of the canister at designated intervals.

Inspect the fuel tank, fuel filler cap, and fuel lines for damage that could cause leakage. Inspect the fuel filler cap for proper sealing ability, and look for any indications of physical damage. On threaded fuel filler caps, inspect the rubber O-ring for cuts, breaks, swelling, or misposition. Inspect threads for wear or damage. Replace any damaged or malfunctioning parts.

TROUBLESHOOTING THE EXHAUST GAS RECIRCULATION (EGR) SYSTEM

Difficult starting, stalling, poor fuel mileage, rough idle, spark knock, or poor overall performance of an engine may indicate a problem with the EGR system, as shown in the troubleshooting chart in Figure 21-8. A quick test should be made of the EGR system to determine if the EGR valve is working properly.

WARNING: Before performing this test, place the transmission in NEUTRAL or PARK. Set the parking brake, and block the drive wheels. With the engine at normal operating temperature, open the throttle while feeling the *diaphragm plate* (Figure 21-9). **WARNING: The EGR valve is hot. It may be necessary to wear gloves to avoid burning your fingers.**

The *actuating diaphragm* with the diaphragm plate should move upward (open) as the engine accelerates and should move downward (close) as the engine returns to idle. A slight vibration of the diaphragm plate may be noticed on some vehicle models. This is due to the actuating diaphragm modulating under light load, but this does not indicate a problem.

If the actuating diaphragm does not move, check for vacuum with the engine at 2,000 RPM. If vacuum is present, replace the EGR valve. If

EXHAUST GAS RECIRCULATION SYSTEM DIAGNOSIS CHART

Condition	Possible Cause	Correction
Engine idles abnormally rough and/or stalls.	EGR valve vacuum hoses misrouted.	Check EGR valve vacuum hose routing. Correct as required.
	Leaking EGR valve.	Check EGR valve for correct operation.
	EGR valve gasket failed or loose EGR attaching bolts.	Check EGR attaching bolts for tightness. Tighten as required. If not loose, remove EGR valve and inspect gasket. Replace as required.
	EGR thermal control valve and/or EGR-TVS.	Check vacuum into valve from carburetor EGR port with engine at normal operating temperature and at curb idle speed. Then check the vacuum out of the EGR thermal control valve to EGR valve. If the two vacuum readings are not equal within ± 1/2 in. Hg. (1.7 kPa), then proceed to EGR vacuum control diagnosis.
	Improper vacuum to EGR valve at idle.	Check vacuum from carburetor EGR port with engine at stabilized operating temperature and at curb idle speed. If vacuum is more than 1.0 in. Hg., refer to carburetor idle diagnosis.
Engine runs rough on light throttle acceleration and has poor part load performance.	EGR valve vacuum hose misrouted.	Check EGR valve vacuum hose routing. Correct as required.
	Check for loose valve.	Torque valve.
	Failed EGR vacuum control valve.	Same as listing in "Engine Idles Rough" condition.
	(TVS open below 130°F.)	Clean EGR passage of all deposits.
	Sticky or binding EGR valve.	Remove EGR valve and inspect. Replace as required.
	Wrong or no EGR gasket(s) and/or Spacer.	Check and correct as required. Install new gasket(s), install spacer (if used), torque attaching parts.
Engine stalls on decelerations.	Control valve blocked or air flow restricted.	Check internal control valve function per service procedure.
	Restriction in EGR vacuum line or valve vacuum signal tube.	Check EGR vacuum lines for kinks, bends, etc. Remove or replace hoses as required. Check EGR vacuum control valve function.
		Check EGR valve for excessive deposits causing sticky or binding operation. Replace valve.
	Sticking or binding EGR valve.	Remove EGR valve and replace valve.
Part throttle engine detonation.	Control valve blocked or air flow restricted.	Check internal control valve function per service procedure.
	Insufficient exhaust gas recirculation flow during part throttle accelerations.	Check EGR valve hose routing. Check EGR valve operation. Repair or replace as required. Check EGR thermal control valve and/or EGR-TVS as listed in "Engine Idles Rough" section. Replace valve as required. Check EGR passages and valve for excessive deposit. Clean as required.
(NOTICE: Non-Functioning EGR valve could contribute to part throttle detonation.)		
	Control valve blocked or flow restricted.	Check EGR per service procedure.
(NOTICE: Detonation can be caused by several other engine variables. Perform ignition and carburetor related diagnosis.)		
Engine starts but immediately stalls when cold.	EGR valve hoses misrouted.	Check EGR valve hose routings.
	EGR TVS system malfunctioning when engine is cold.	Perform check to determine if the EGR thermal control valve and/or EGR-TVS are operational. Replace as required.
(NOTICE: Stalls after start can also be caused by carburetor problems.)		

Figure 21-8. Typical diagnosis chart for an EGR system. (Courtesy of Chevrolet Motor Division, General Motors Corporation)

there is no vacuum, check the vacuum hose for restrictions. If there is no restriction in the hose and the engine is thoroughly warmed up, replace the thermostatic vacuum control valve connected to the EGR valve. It is important that all hoses and connections be free from leaks. Any hoses or components that are leaking must be replaced.

If the EGR valve is suspected of causing a problem, or if there is a possibility that the EGR valve passages are plugged, a more detailed test should be performed. Connect an accurate tachometer to the engine. With the engine at normal operating temperature, run it at 2,000 RPM in NEUTRAL. When the vacuum hose is disconnected from the EGR valve, engine speed should increase. If it does, the EGR valve is operating properly, and the passages are clear.

If the speed does not increase, check under the actuating diaphragm for movement as the vacuum hose is connected. If there is no movement, but there is vacuum, replace the EGR valve. If the actuating diaphragm moves, but the speed does not increase, remove and clean the EGR valve. Also, clean the passages in the manifold.

To test the thermostatic vacuum control valve connected to the EGR valve, first allow the engine to cool so that the thermostatic vacuum control valve cools to at least 60° F. At this temperature, the valve should block vacuum to the EGR valve. If it does not, replace thermostatic vacuum control valve.

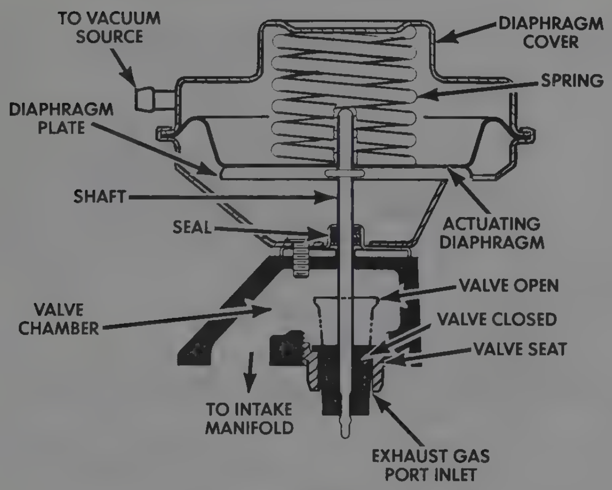

Figure 21-9. The EGR valve should open as the engine is accelerated and close when it returns to idle. (Courtesy of Chevrolet Motor Division, General Motors Corporation)

TROUBLESHOOTING THE IGNITION TIMING CONTROL

Ignition timing should always be checked and adjusted during a tune-up. If ignition timing cannot be adjusted to specifications, the problem may be a malfunctioning ignition timing control component.

If the system is equipped with a *spark delay valve*, it may be plugged. To check the spark delay valve, first start the engine and let it warm to operating temperature. Remove the *vacuum hose* (or *line*) from the vacuum advance mechanism, and hold your finger over the end of the vacuum hose (Figure 21-10). Slowly increase engine speed to approximately 2,000 to 2,500 RPM. In about 15 seconds, the vacuum hose should stick to your finger (because of suction), indicating that the spark delay valve is operating correctly. However, if you feel a strong vacuum immediately upon increasing engine speed, the spark delay valve should be replaced. Also, if no vacuum (suction) is felt after 30 seconds, the spark delay valve should be replaced.

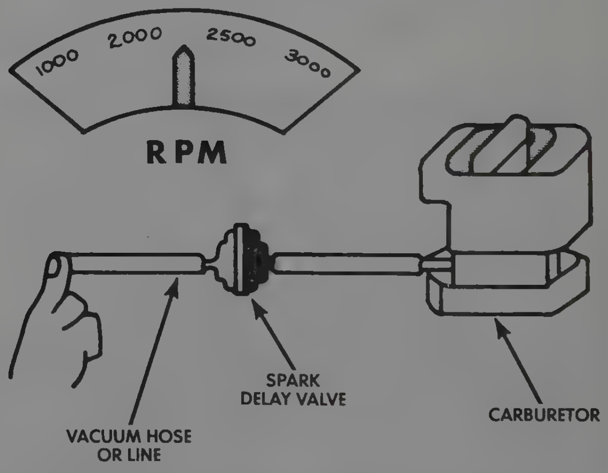

Figure 21-10. The spark delay valve operates when there is no vacuum for about 15 seconds.

The *thermostatic vacuum control valve* should be checked with a *vacuum gage*. Install the gage on the connection that goes to the *distributor vacuum advance mechanism* (Figure 21-11). With the other hoses or lines connected and the engine temperature below normal operating temperature, the vacuum gage should read near zero inches of mercury (in.

Hg.). As the engine warms us, the reading should reach 16 in. Hg. or more. If this reading is not obtained, and the source of vacuum is satisfactory, the thermostatic vacuum control valve should be replaced.

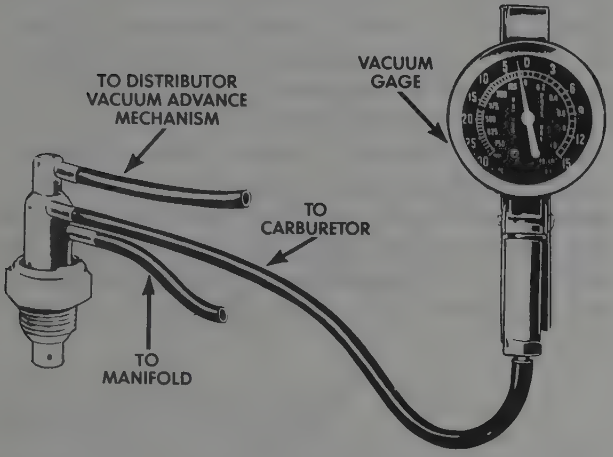

Figure 21-11. Checking a themostatic vacuum control valve with a vacuum gage. (Courtesy of Chevrolet Motor Division, General Motors Corporation)

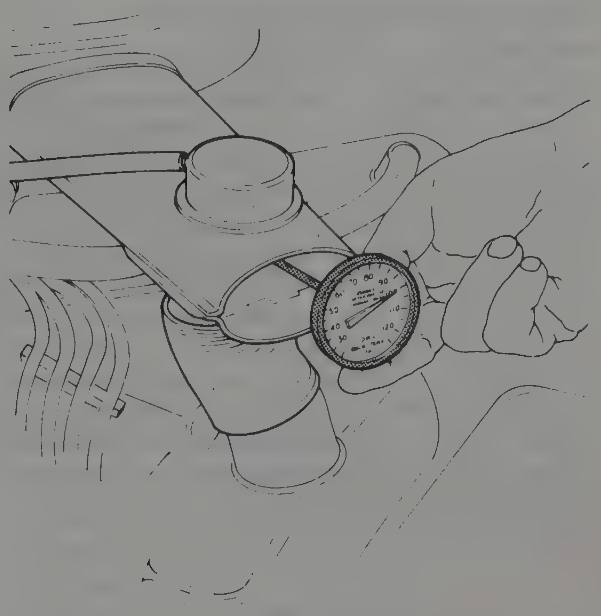

Figure 21-12. Check inlet air temperature when troubleshooting the heated intake air system. (Courtesy of Chrysler Corporation)

TROUBLESHOOTING THE HEATED INTAKE AIR SYSTEM

Improper functioning of the *heated intake air system* will affect performance, as well as vehicle exhaust emissions. To determine whether it is functioning properly: Make sure all vacuum hoses and the stove-to-air cleaner flexible connector are properly attached and in good condition. With a cold running engine and ambient temperature in the engine compartment less than 50° F, the door (valve plate) of the damper assembly in the snorkel should be in the hot air delivery mode (up position).

With the engine warmed up and running, check the air temperature entering at the *snorkel* or at the *sensor* with a thermometer (Figure 21-12). (The sensor is not shown in Figure 21-12.). When the air temperature entering the snorkel is 82° F or higher, the damper assembly's door should be in the down position (cold air delivery mode). Remove the air cleaner from the engine and allow it to cool to 50° F. With 20 in.Hg. (vacuum) applied to the sensor, the damper assembly's door should be in the up position (hot air delivery mode). If it is not, check the vacuum motor's diaphragm for proper operation as follows:

Apply vacuum with a hand-operated *vacuum pump* (Figure 21-13). The *damper assembly door* should lift off the bottom of the *snorkel* at not less that 5.5 in.Hg. and should be fully in the up position with no more than 8.5 in.Hg. Apply 20 in.Hg. (vacuum) to test for leakage. The vacuum motor diaphragm should not bleed down more than 10 in.Hg. in five minutes.

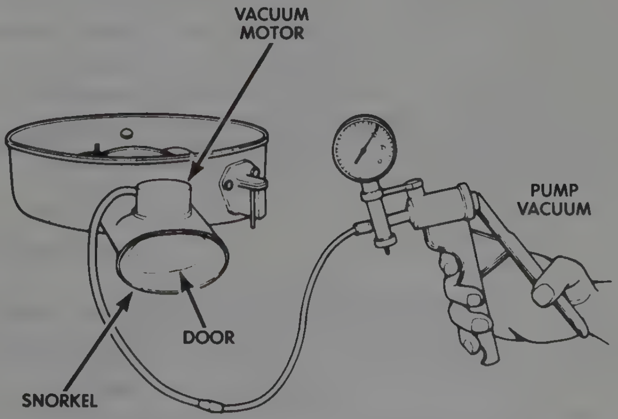

Figure 21-13. Checking vacuum motor diaphragm operation. (Courtesy of Chrysler Corporation)

TROUBLESHOOTING THE AIR INJECTION SYSTEM

A problem in the air injection system can result in loss of efficiency and noisy operation. Figure 21-14 shows a typical diagnosis chart used to troubleshoot an air injection system. Engine belts must be checked for proper tension, for wear, for cracks, or for any signs of deterioration to make certain that the *air pump* is being operated at satisfactory RPM. A slipping belt could result in below-capacity air pump operation and an increase in exhaust pollutants (emissions). The air injection system's hoses and fittings must be checked at the same time for looseness and deterioration and replaced or tightened as necessary.

The *check valve* should also be inspected whenever the hose from the diverter valve to the check valve is disconnected or if check valve failure is suspected. An air pump that has failed and that shows signs of exhaust gas in it indicates check valve failure. To test the check valve, blow through it toward the *cylinder head*, then try to draw back air through the check valve. Airflow should occur only in the direction toward the cylinder head.

To check the *diverter valve*, first stabilize the engine at idle speed. Check to see that no air is escaping from the diverter valve. Momentarily pinch the vacuum hose running to the diverter valve. Air should exhaust from the diverter's silencer chamber for about five seconds when

AIR INJECTION SYSTEM DIAGNOSIS CHART

Condition	Cause	Correction
Excessive belt noise	Loose belt	Tighten belt to correct tension
	Seized pump	Replace pump assembly
Excessive pump noise, chirping, rumbling or knocking	Leak in hose	Locate source of leak and correct
	Loose hose	Reassemble and replace or tighten hose clamp
	Hose touching other engine parts	Adjust hose position
	Diverter valve failure	Replace valve
	Check valve failure	Replace valve
	Pump mounting fasteners loose	Retorque all mounting screws
	Centrifugal fan damaged	Replace centrifugal fan
	Pump failure	Replace pump assembly
No air supply	Loose belt	Tighten belt to correct tension
	Leak in hose	Locate source of leak and correct
	Leak at hose fitting	Reassemble and replace or tighten hose clamps
	Diverter valve failure	Replace valve
	Check valve failure	Replace valve
	Pump failure	Replace pump assembly

Figure 21-14. Typical air injection system diagnosis chart. (Courtesy of Chevrolet Motor Division, General Motors Corporation)

the vacuum hose is released. In most cases, the exhausting air can be heard. If in doubt, hold your hand over the diverter valve exhaust port. An inoperative or leaking diverter valve should be replaced.

If the air injection system uses an *aspirator* or *pulsing valve* instead of an air pump, it should be checked also. To determine if the aspirator valve has failed, first disconnect the hose from the aspirator inlet. With the engine at idle and the vehicle in NEUTRAL, the negative (−) pressure (vacuum) exhaust pulses can be felt at the aspirator inlet. If hot exhaust gas is escaping from the aspirator inlet, the aspirator valve has failed and should be replaced.

TROUBLESHOOTING THE FEEDBACK SYSTEM

Feedback systems use a computer to monitor the amount of oxygen in the exhaust gas and to adjust the carburetor or EFI air-fuel mixture accordingly. The computer has the capability of diagnosing problems that are most likely to occur in the feedback system.

Each manufacturer uses a different procedure for troubleshooting its feedback system. (Always check the appropriate service manual for the vehicle being serviced.) Generally, most problems are first indicated by a warning sign on the instrument panel — usually, "check engine." When the vehicle is taken in for service, the tune-up technician activates the computer memory to determine the problem. The computer memory may be activated by a switch under the hood, a switch under the instrument panel, or by using a clip lead or jumper wire on certain terminals of the computer's connector harness.

When the computer memory has been activated, a flashing display appears on the vehicle instrument panel. The display is usually coded and referred to as a **trouble code**. It consists of letters, numbers, or flashes of light. A set of charts, located in the service manual, is used to decode the display. For example: A series of a specific number of repetitive flashes indicates a particular problem. By consulting the charts in the service manual, the component(s) causing the problem can be identified. The tune-up technician then replaces the component(s), one at a time, until the computer indicates that the problem no longer exists.

KEY TERMS

Trouble codes: Flashing display on the dashboard that pinpoints a problem in a feedback system.

Vehicle emission control information label: An under-the-hood label that describes the type of emission equipment on the vehicle and gives its specifications.

SELF-CHECK

1. What information is found on a vehicle emission control information label?
2. How is an exhaust analyzer used to troubleshoot an emission system?
3. How is a PCV system checked?
4. What is an indication of a problem in the evaporation control system?
5. What are some of the problems that occur when the EGR system does not operate correctly?
6. How is an EGR valve checked?
7. How is a spark delay valve checked?
8. What tools are necessary to check a heated intake air system?
9. How is an air injection system check valve checked?
10. How is a diverter valve checked?

DISCUSSION TOPICS AND ACTIVITIES

1. Use a vehicle emission control information label to identify all the emission control equipment on a vehicle.
2. Use a vacuum hose routing diagram to remove and replace a set of vacuum hoses.

CERTIFICATION PRACTICE

1. A malfunctioning EGR system can cause:
   A. Difficult starting
   B. Stalling
   C. Poor fuel mileage
   D. All of the above

2. Emission system noise can be caused by a malfunction in the:
   A. Vacuum system
   B. Air injection system
   C. EGR system
   D. PCV system
3. Rough idle can be caused by a malfunction in the:
   A. EGR system
   B. PCV system
   C. Both A and B
   D. Neither A nor B
4. Improper operation of the heated intake air system affects:
   A. Performance
   B. Emissions
   C. Both A and B
   D. Neither A nor B
5. Improper operation of the air injection system can result in:
   A. Noisy operation
   B. Loss of efficiency
   C. Both A and B
   D. Neither A nor B

ANSWERS

1: D, 2: B, 3: C, 4: C, 5: C

Unit 22 SERVICING THE EMISSION CONTROL SYSTEM

Emission control system service is essential to keep emission levels low and obtain maximum performance from an engine. Service intervals for emission control system components are usually specified by the vehicle manufacturer. In addition, some component maintenance is performed whenever troubleshooting procedures indicate a malfunction or problem. In either case, a tune-up is not complete until the emission control system is operating according to specifications.

DEVELOPING JOB COMPETENCIES

When you finish reading and studying this unit, you should be able to:

- Remove and replace a PCV valve.
- Remove and replace a vapor canister filter.
- Remove and replace an EGR valve.
- Service an air injection system.
- Service a heated air intake system.

REMOVAL AND REPLACEMENT OF A PCV VALVE

To replace a *PCV valve* (Figure 22-1), pull it out of the *rubber grommet* in the *rocker arm cover*. Remove the carburetor *hose* from the old PCV valve, and place a new PCV valve in the rocker arm cover. Clean the carburetor hose with combustion chamber conditioner or similar solvent and allow it to dry.

To service a PCV valve, first make sure that the passage into the carburetor body is clear. If it is plugged, use a pipe cleaner to clear the obstruction. Also, disconnect the hose from the crankcase inlet air cleaner. Inspect the hose from the crankcase inlet air cleaner to the carburetor air cleaner. Clean it if necessary. Remove the crankcase inlet air cleaner, and wash it thoroughly in kerosene or similar solvent. Lubricate the filter by inverting the crankcase inlet air cleaner and filling with SAE 30 engine oil. Position the air cleaner to allow excess oil to drain thoroughly through the vent nipple. Reconnect the crankcase inlet air cleaner, and attach the hose.

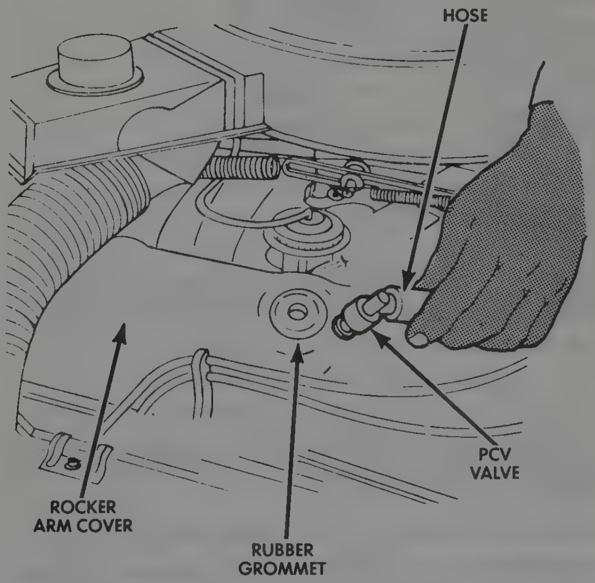

Figure 22-1. Removing a PCV valve. (Courtesy of Chrysler Corporation)

REMOVAL AND REPLACEMENT OF A VAPOR CANISTER FILTER

To service the evaporation control system, replace the *filter* located at the bottom of the *vapor canister* (Figure 22-2). This is accomplished as follows.

Mark the hoses on top of the vapor canister to aid in correct reassembly later, and remove the hoses from the top of the canister. Remove the *mounting screw* holding the vapor canister to the *mounting bracket*, and remove the vapor canister. Remove the old filter and replace it with a new filter. Reassemble the vapor canister into the mounting bracket and secure it in place. Attach the hoses that were removed earlier.

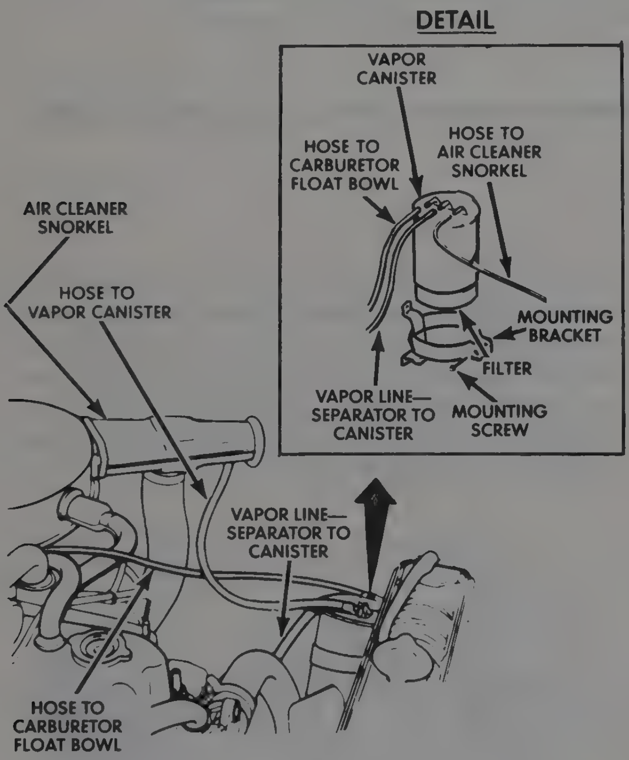
DETAIL
VAPOR CANISTER
HOSE TO CARBURETOR FLOAT BOWL
HOSE TO AIR CLEANER SNORKEL
MOUNTING BRACKET
FILTER
VAPOR LINE—SEPARATOR TO CANISTER
MOUNTING SCREW
AIR CLEANER SNORKEL
HOSE TO VAPOR CANISTER
VAPOR LINE—SEPARATOR TO CANISTER
HOSE TO CARBURETOR FLOAT BOWL

Figure 22-2. Typical location and connections for a vapor canister. (Courtesy of American Motors Corporation)

REMOVAL AND REPLACEMENT OF AN EGR VALVE

If troubleshooting procedures indicate a malfunction in the EGR valve, it must be removed and cleaned or replaced. To remove an EGR valve (Figure 22-3), first remove the air cleaner and disconnect the *vacuum hose* from the *EGR valve*. Remove the *mounting bolts* from the manifold, and lift the EGR valve, *gasket*, and spacer (if the vehicle is so equipped). Discard the gasket and clean the *mating surface*.

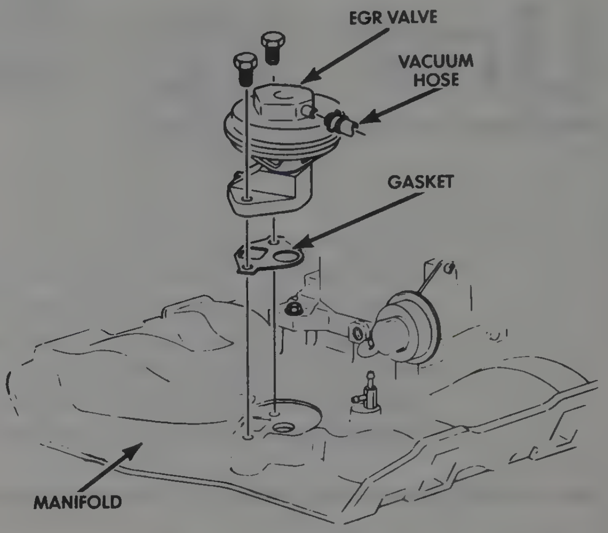
EGR VALVE
VACUUM HOSE
GASKET
MANIFOLD

Figure 22-3. Removing an EGR valve. (Courtesy of Cadillac Motor Car Division, General Motors Corporation)

The EGR valve should be inspected for carbon deposits, especially in the *valve* and *valve seat* area (Figure 22-4). If deposits are found, the EGR valve should be cleaned. Apply a *manifold heat control valve solvent* to the valve and valve seat area. Allow the deposits to soften. Then open the valve by disconnecting the vacuum line and attaching a vacuum pump. Use the vacuum pump to create a vacuum to open the valve. The deposits may then be scraped from the valve and valve seat area with a suitable sharp-edged tool.

CAUTION: Care should be exercised during the cleaning operation to prevent spilling solvent on the actuating diaphragm, as this may cause actuating diaphragm failure. Do not push on diaphragm to operate the valve; use the vacuum source only.

If wear of the stem or other moving components is noted, the EGR valve should be replaced.

If inspection of the EGR passages in the intake manifold indicates excessive build-up of carbon deposits, the passages should be cleaned. Spray manifold heat control solvent on the deposits to loosen them. Scrape away deposits, and use a shop vacuum cleaner to remove loose particles. Make sure all loose particles are completely removed so that they cannot clog the EGR valve or enter the combustion chamber.

To install the cleaned valve or a new valve, position a new gasket on the intake manifold. Place the EGR valve into position and secure it with the mounting bolts. Tighten to the specified torque. Connect all vacuum hoses. For hose routings, refer to the under-the-hood vacuum hose routing diagram. Replace the air cleaner, and start the engine. Check again for correct EGR valve operation.

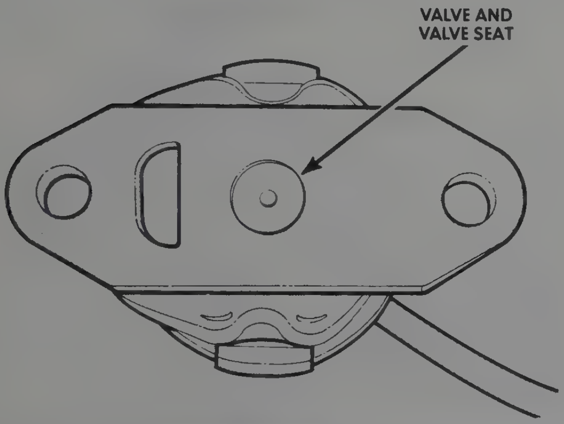

Figure 22-4. The valve and valve seat area of the EGR valve should be inspected for carbon deposits. (Courtesy of Chrysler Corporation)

SERVICING AN AIR INJECTION SYSTEM

If troubleshooting procedures indicate a problem in the air injection system (Figure 22-5), the malfunctioning component must be removed and replaced. The main components, as mentioned in Unit 20, are the *air pump, diverter valve, check valve,* and *connecting hoses*.

Air Pump

For proper operation of the air pump, it is necessary that the *air pump drive belt* (Figure 22-5) be in good condition and adjusted to the specified tension. Check the condition of the air pump drive belt, and adjust the tension according to specifications at the intervals specified by the vehicle manufacturer.

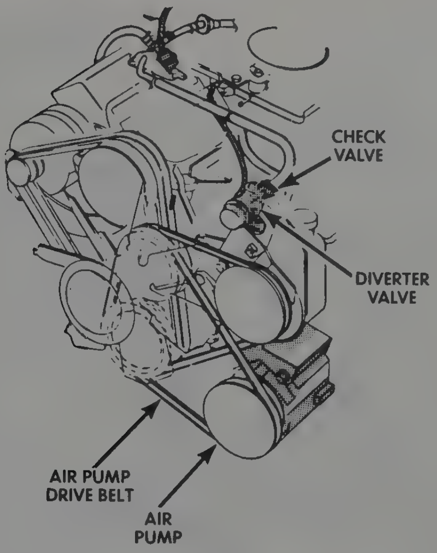

Figure 22-5. Air injection system components. (Courtesy of Chrysler Corporation)

To adjust the belt (Figure 22-6), first loosen the air pump *pivot bolt* and *adjusting bolt*. Move the air pump until belt tension is correct. Tighten the adjusting bolt and pivot bolt. Use a belt tension gage to check adjustment.

CAUTION: Do not pry on the pump housing. Distortion of the housing will result in extensive damage to the air pump.

A worn *air pump pulley* can be removed on the car (Figure 22-6). Keep the air pump pulley from turning by compressing the air pump drive belt. Then loosen the *pulley bolt*. Remove the air pump drive belt, and then remove the pump pulley.

To install a pump pulley, follow the reverse order of removal. Torque the pump pulley bolt to specifications. Install and adjust the drive belt as described previously in this unit. Recheck the drive belt tension, and adjust if required.

To remove an air pump (Figure 22-6), first remove the bolts securing the *diverter valve* to the air pump, and position the diverter valve and *connecting hoses* out of the way. Remove the *adjusting bolt* and the *pivot bolt and nut*. Then remove the air pump by lifting it straight up.

To replace the air pump, position it in the *mounting bracket* and loosely install the pivot bolt and nut and the adjusting bolt. Using a new gasket, position the diverter valve to connect it

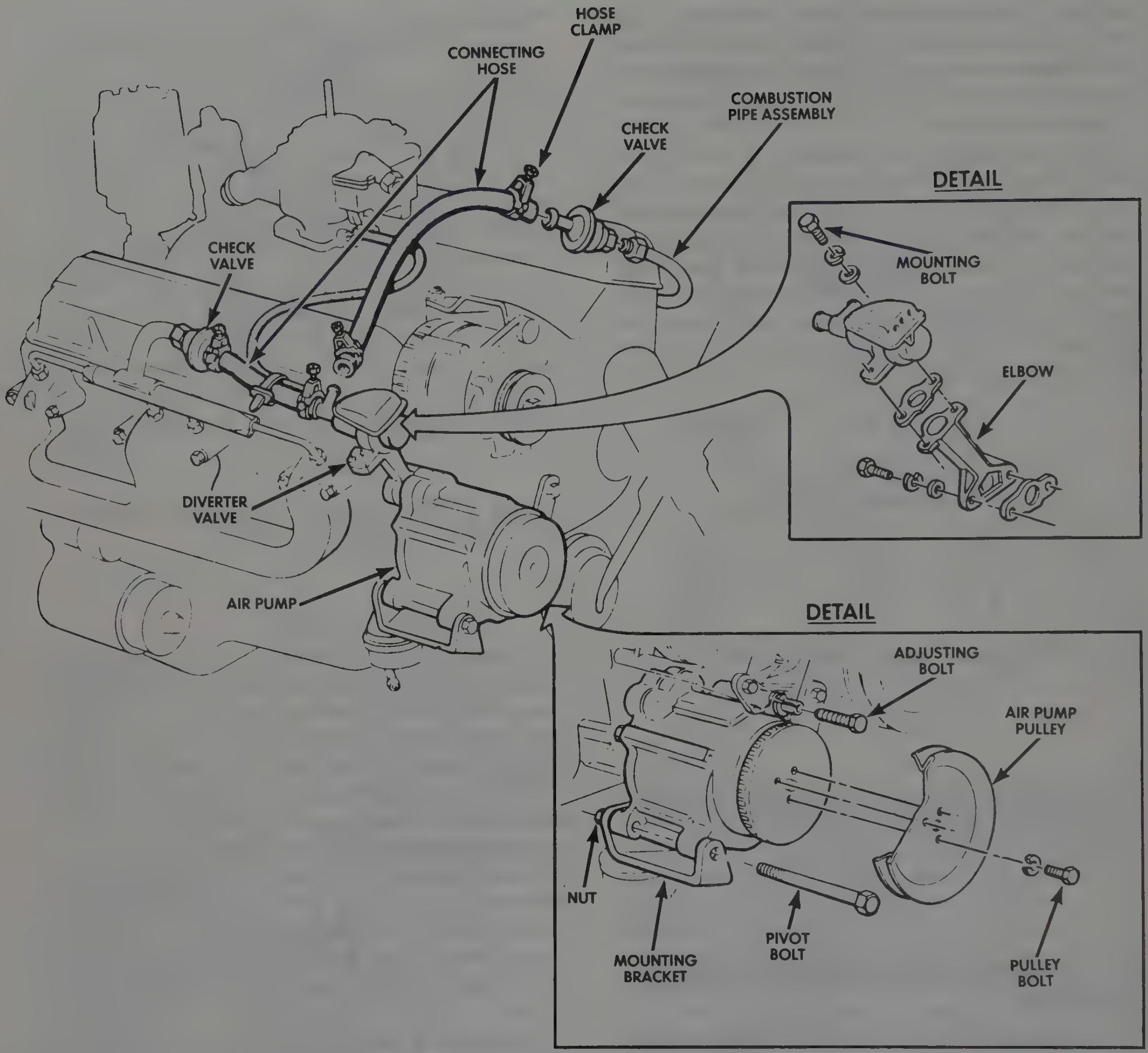
HOSE CLAMP
CONNECTING HOSE
COMBUSTION PIPE ASSEMBLY
CHECK VALVE
DETAIL
CHECK VALVE
MOUNTING BOLT
ELBOW
DIVERTER VALVE
AIR PUMP
DETAIL
ADJUSTING BOLT
AIR PUMP PULLEY
NUT
MOUNTING BRACKET
PIVOT BOLT
PULLEY BOLT

Figure 22-6. Servicing air injection system components. (Courtesy of Chevrolet Motor Division, General Motors Corporation)

to the air pump and secure it with two bolts. (If the diverter valve is attached to the air pump with an elbow, replace the gaskets at each end of the elbow.) Torque all bolts to specifications, and make sure the air pump drive belt is properly tensioned.

Diverter Valve

If the *diverter valve* requires replacement (Figure 22-6), disconnect all lines and hoses, and remove the diverter valve from the *air pump* or from the *elbow*. Install the diverter valve, connecting it to the air pump or to the elbow, using a new gasket. Torque the diverter valve mounting bolts to specifications. Attach all the lines and hoses that were removed. Check the air injection system for leaks.

Check Valve

Inspect the check valve for signs of burning or clogging. If it is burned or clogged with carbon, it should be replaced. To replace the check valve (Figure 22-6), first remove the *hose clamp* from the *connecting hose*. Pull the hose off the check valve. Unscrew the check valve from the *combustion pipe assembly*. Install the new check valve by threading it onto the combustion pipe assembly. Attach the connecting hose and hose clamp.

Air Injection Hoses and Tubes (Lines)

Air injection hoses (Figure 22-7) should be inspected for leaks and replaced as necessary. *Air injection tubes* (Figure 22-8) should be inspected whenever the *exhaust manifolds* are removed. Check the air injection tubes for carbon build-up and for warped or burned tubes. Remove any carbon build-up with a wire brush. Warped or burned air injection tubes must be replaced as an assembly.

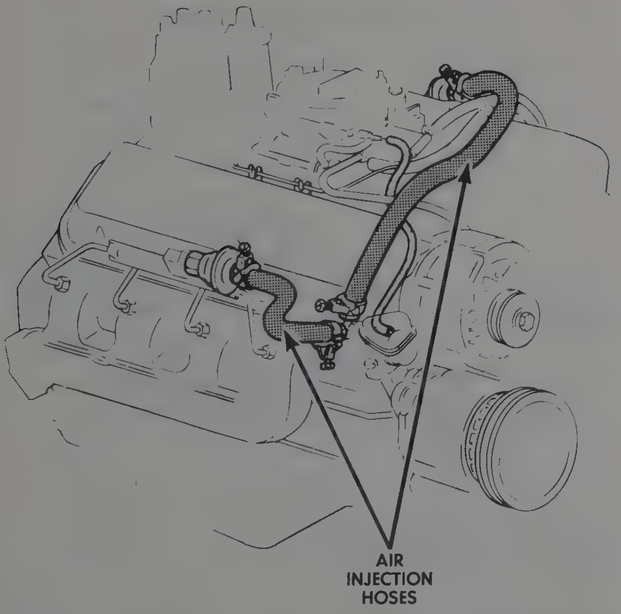

Figure 22-7. Air injection hoses. (Courtesy of Chevrolet Motor Division, General Motors Corporation)

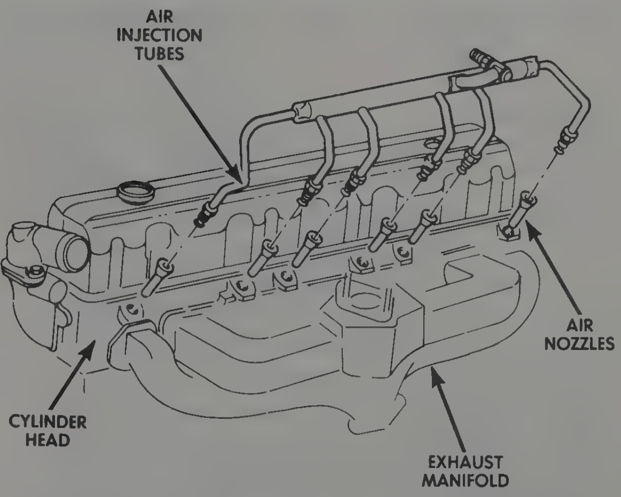

Figure 22-8. Air injection tubes and air nozzles. (Courtesy of Chevrolet Motor Division, General Motors Corporation)

SERVICING A HEATED AIR INTAKE SYSTEM

If a heated air intake system does not operate properly, the vacuum motor may need replacement. To replace the vacuum motor, first remove the air cleaner. Disconnect the vacuum hose from the *vacuum motor*. Drill through the *weld on tab* (lower left insert of Figure 22-9), and then tip the vacuum motor slightly forward to disengage the *lock* and rotate counterclockwise. When the vacuum motor is free from the *snorkel*, slide it to one side to disengage the *linkage* from the damper assembly.

With the vacuum motor removed, check the damper assembly for freedom of movement. When it is raised to the up position (hot air delivery mode), it should fall freely when released. If it does not, check for interference or foreign matter in the snorkel. Also, check all linkage for foreign matter or obstructions.

To install the replacement vacuum motor, attach the damper assembly linkage to the vacuum motor. Position the locks into the openings in the snorkel and turn clockwise until firmly engaged. *Pop rivet* the tab in place (upper right insert of Figure 22-9). Apply vacuum to the vacuum motor, and make sure that the damper assembly operates freely. Replace the air cleaner.

The temperature sensor must be replaced if it is defective. Remove the air cleaner, and detach the hoses connected to the temperature

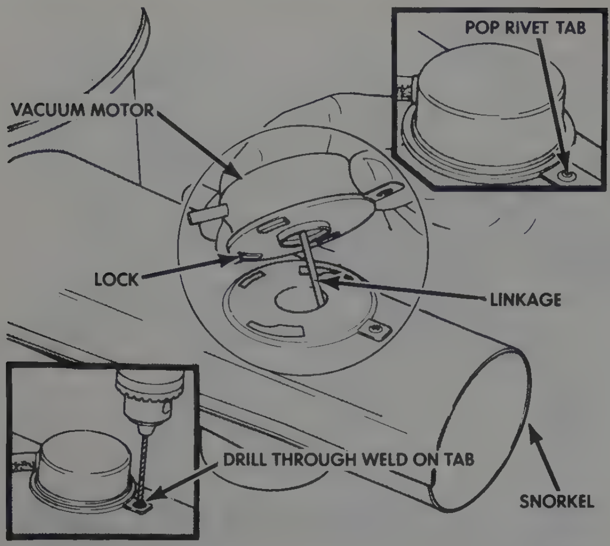

Figure 22-9. Removing and replacing the vacuum motor. (Courtesy of Chrysler Corporation)

sensor. Use a screwdriver to pry off the *retaining clip* (Figure 22-10) after bending its tabs up. Install the new temperature sensor and gasket in the same position as the old one. Press the retaining clip into position. Bend the tabs down. Connect the hoses, and install the air cleaner.

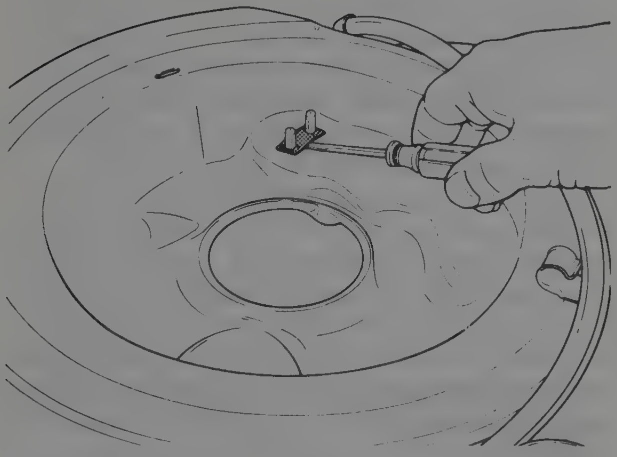

Figure 22-10. Removing the temperature sensor retaining clip. (Courtesy of Chevrolet Motor Division, General Motors Corporation)

SERVICING THE CATALYTIC CONVERTER

Because the catalyst in a catalytic converter can become contaminated and destroyed by the lead additives used in gasoline, all cars equipped with catalytic converters must use unleaded fuel. To prevent the use of leaded fuel in these cars, their fuel tank filler necks are too small in diameter to accommodate the pump nozzles for leaded fuel in service stations. In addition, all vehicles equipped with catalytic converters have a *restrictor assembly* in the *fuel tank filler tube* (Figure 22-11) that prevents insertion of leaded-fuel pump nozzles. *Federal law prohibits pumping leaded fuel into any car that requires unleaded fuel.*

Federal regulations require that catalytic converters have a service life of at least 50,000 miles. No service should be necessary during this period. Some catalytic converters can be serviced to remove and replace the contaminated pellets (catalyst) with fresh material (catalyst). Other catalytic converters cannot be disassembled and are therefore replaced as a unit, just as a muffler is.

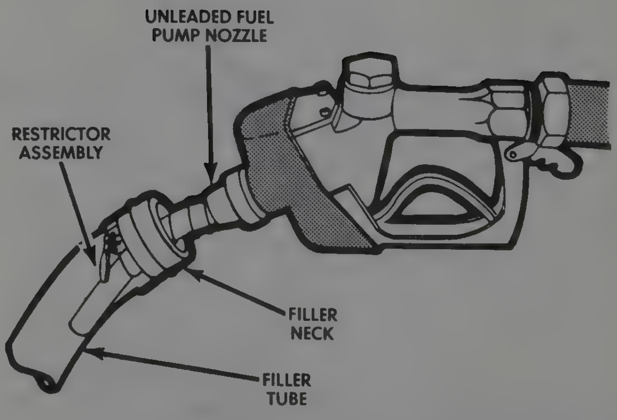

Figure 22-11. A restrictor assembly prevents leaded-fuel pump nozzles from entering the tank filler neck of a vehicle equipped with a catalytic converter. (Courtesy of Chrysler Corporation)

SELF-CHECK

1. When are emission control system components serviced?
2. How is a PCV valve replaced?
3. What other parts or components should be cleaned when servicing a PCV valve?
4. How is a vapor canister filter replaced?
5. Where is the vapor canister filter located?
6. How is an EGR valve replaced?
7. What parts of an EGR valve should be cleaned?
8. How is an air injection pump drive belt adjusted?
9. How is an air injection pump replaced?
10. How is a heated air intake system vacuum motor replaced?

DISCUSSION TOPICS AND ACTIVITIES

1. Use a shop engine to practice removing and replacing emission control system components.
2. Compare the emission control system maintenance schedules from a vehicle several years old with a current one. Are there more or less services to perform? Why?

CERTIFICATION PRACTICE

1. Service of emission control system components is based upon:
   A. Mileage interval
   B. Time interval
   C. Both A and B
   D. Neither A nor B
2. When a PCV valve is malfunctioning, it should be:
   A. Adjusted
   B. Disassembled
   C. Replaced
   D. None of the above
3. When installing an EGR valve, the tune-up technician should:
   A. Use a new gasket
   B. Check the manifold passages
   C. Torque the mounting bolts
   D. All of the above
4. In order to remove an air injection pump, the tune-up technician must remove:
   A. The mounting bolts connecting the diverter valve to the air pump
   B. The drive belt
   C. All lines and hoses
   D. All of the above
5. When servicing the evaporation control system, the tune-up technician should replace the:
   A. Vapor canister filter
   B. Vapor canister charcoal
   C. Both A and B
   D. Neither A nor B

ANSWERS

1:C, 2:C, 3:D, 4:D, 5:A

GLOSSARY

A

Abnormal display patterns: Oscilloscope display patterns that show a problem in the firing, intermediate, or dwell section.

Acceleration system: A system in the carburetor that provides a rich air-fuel mixture for acceleration.

Active material: Sponge lead and lead peroxide used in the plates of a battery.

Advance systems: Ignition system components designed to regulate the time the spark occurs in the combustion chamber.

Air bleed: Passages for air to enter the fuel in the carburetor.

Air cleaner: A filter assembly mounted above the carburetor to filter, or clean, the air before it enters the engine.

Air injection system: A system for adding air at the exhaust port to burn the hydrocarbons (HC) remaining in the exhaust gas as it leaves the combustion chamber.

Air pump: A pump that supplies air to exhaust port injection nozzles or to a catalytic converter to reduce hydrocarbons (HC) and carbon monoxide (CO).

Air regulator: An EFI system component that provides extra air for fast idle.

Airflow meter: An airflow measuring device that has a potentiometer to provide a variable voltage signal based on airflow into the engine.

Airflow system: An airflow-sensitive timed EFI subsystem. Its purpose is to provide for the flow of air into the engine. The amount of air is measured and the measurement is used to determine the amount of fuel injected.

Alternating current: Current that changes from positive (+) to negative (−) at a regular cycle.

Alternator output test: A test that measures the alternator's ability to produce its rated output.

Alternator: An engine-driven, alternating-current generator.

Ammeter: An electrical meter that measures the amount of current flow in an electrical circuit.

Amperage: The rate of current flow in an electrical circuit.

Armature: One of the two main parts of the starter motor.

Artificial enrichment: A method of metering propane into the engine at idle speed to provide a temporarily rich mixture to help in adjusting the idle speed. It is also referred to as the propane-enrichment method.

Atom: The smallest particle into which an element can be divided and still retain its characteristics as an element.

Atomization: Breaking liquid fuel into very small droplets.

Available voltage: The maximum voltage an ignition system is capable of producing under a given operating condition.

B

Basic timing: Timing established by the position of the distributor in the engine.

Battery electrolyte: The acid solution used in battery cells that can damage the skin or eyes as well as clothing.

BDC: Abbreviation for bottom dead center.

Breaker point alignment: The bending of the stationary breaker point arm to ensure the correct closing, or mating, of the breaker points.

Breaker point gap: The space between the stationary and movable breaker points when the rubbing block is resting on a distributor cam lobe high point.

Breaker point spring tension: The force exerted by the breaker point spring to close the breaker points.

Breaker points: A mechanical switch used to open and close current flow to the coil primary winding.

Bypass circuit: The circuit that sends ignition current through a ballast resistor when the vehicle is running and bypasses the ballast resistor when the vehicle is cranked.

Bypass valve: A valve assembly used to direct oil around a clogged oil filter.

C

Capacitive discharge ignition system: An aftermarket ignition system that uses the energy stored in a capacitor to develop high voltage.

Capacitor: An electrical device that stores energy.

Carbon monoxide: A colorless, odorless, poisonous gas formed when there is not enough oxygen in the air-fuel mixture to completely burn the fuel. It is present in the car's exhaust. It is abbreviated CO.

Carburetor: A component of the fuel system that mixes air and fuel in the correct proportions to burn in the engine combustion chamber.

Catalyst: A substance that promotes a chemical reaction without becoming part of the chemical reaction.

Catalytic converter: A device that promotes oxidation (burning) of exhaust emissions.

Cell: A basic component of the battery capable of developing about 2 volts.

Centrifugal advance mechanism: An ignition timing system component sensitive to engine speed and used to advance ignition spark.

Choke adjustment: Turning the thermostatic spring housing cover or bending the choke linkage to adjust the choke to specifications.

Choke system: A system that provides a richer air-fuel mixture in the carburetor for cold starts.

Circuit: A complete path that allows current flow.

Circuit protector: Fuses, fusible links, or circuit breakers used to protect against an overload or short or ground.

Coil primary resistance: A resistance measurement taken with the ohmmeter connected at both ends of the primary winding.

Coil secondary resistance: A resistance measurement taken with the ohmmeter connected at both ends of the secondary winding.

Cold start valve: An EFI component that provides for fuel enrichment to all cylinders for starting.

Combustion: The controlled burning process of the air-fuel mixture in the engine's combustion chamber.

Combustion chamber: The part of the engine in which the burning of air and fuel takes place.

Compression ratio: A comparison of the volume for air and fuel when the piston is at bottom dead center with the volume at top dead center.

Compression stroke: One of the strokes of the four-stroke-cycle engine, during which the air is compressed.

Compression tester: A tool that measures compression pressure in a cylinder.

Condenser: The capacitor in the ignition primary circuit that prevents breaker point arcing and provides efficient ignition coil induction.

Conductor: A material that allows current to flow.

Connecting rod: An engine part that connects the piston to the crankshaft.

Coolant: A liquid in the cooling system that carries away (dissipates) heat — usually a mixture of ethylene glycol and water.

Coolant pump: A pump that circulates coolant through the engine block. It is sometimes referred to as a water pump.

Cooling system: An engine system that keeps the engine's temperature within proper operating limits.

Crankshaft: An offset shaft to which the connecting rods are attached.

Curb idle: An idle speed setting at normal operating temperatures.

Current: The flow of electrons in an electrical circuit. It is measured in amperes.

Cylinder: A tube, closed at one end, in which an engine's piston moves up and down.

Cylinder leakage tester: A tool that reveals whether there are any leaks from the cylinder when the piston is on the compression stroke.

Cylinder number: A number assigned to each cylinder of an engine for identification.

D

Dashpot: A control device that reduces the rate of throttle plate closure when the accelerator pedal is suddenly released.

Dealership: A business facility organized to sell and service new and used automobiles.

Delta RPM: The speed change associated with propane-assisted idle adjustments.

Detailer: A service worker who cleans an automobile to prepare it for sale or delivery to a customer.

Diode: A solid state electronic component that changes, or rectifies, alternating current to direct current by allowing current to pass through it freely in one direction but not in the other.

Direct current: Current that does not change from positive (+) to negative (−).

Distributor: An ignition system component that opens and closes the primary circuit to the ignition coil and distributes secondary ignition current to the correct cylinder at the correct time.

Distributor cap: The top part of the distributor that fits over the distributor housing and has metal inserts for the spark plug cable electrical connection.

Distributor tester: A diagnostic tester used for a number of distributor service operations.

Diverter valve: An EFI component designed to prevent backfire by directing air from the air pump to the atmosphere during deceleration.

Dual breaker point distributor: A distributor with two sets of breaker points that are out of phase with each other.

Dual pickup coil distributor: A distributor with two sets of pickup coils that are out of phase with each other.

Dwell: The number of degrees that the breaker cam rotates while the breaker points are closed.

Dynamometer: A testing device that allows the tune-up technician to simulate various driving conditions to help determine the vehicle's performance ability.

E

EGR valve: The part of the exhaust gas recirculation (EGR) system that directs exhaust gas into the intake manifold to mix with the incoming air-fuel mixture.

Electricity: A form of energy produced by the flow of electrons from one atom to another.

Electrolyte: The acid solution of water and sulfuric acid in a battery cell.

Electronic control system: An airflow-sensitive timed EFI subsystem. Its purpose is to sense engine operating conditions and regulate the quantity of fuel injected in relation to airflow.

Electronic control unit: A component of an electronic fuel injection (EFI) system.

Electronic ignition distributor: A distributor that uses solid state components instead of breaker points to develop high-voltage current.

Electronic ignition system: An ignition system that uses solid state components instead of breaker points to develop high-voltage current.

Emission control system: A system that reduces pollution from an automobile.

Evaporation control system: A system that prevents fuel (gasoline) vapors from escaping into the atmosphere from the fuel tank and carburetor.

Exhaust gas recirculation system: A system that reduces oxides of nitrogen (NO_x).

Exhaust stroke: One of the four strokes of a four-stroke-cycle engine, during which the exhaust gas is expelled.

F

Fan: A device that draws air through the radiator core to cool the engine.

Fast idle: An idle speed setting when the choke is activated and the fast idle cam is in use during engine warm-up.

Fast idle cam: Linkage connected to the choke that allows a fast idle speed during warm-up.

Feedback system: A system that senses the engine air-fuel ratio and corrects it to the ideal air-fuel ratio.

Field winding: One of the two main parts of the starter motor used to create a magnetic field.

Firing order: The sequence in which each cylinder is ready for a power stroke.

Firing voltage: The amount of voltage required to produce a spark across the electrodes of a spark plug.

Float drop: The distance that a float can lower in a float bowl.

Float level: The adjustment that determines how high the fuel rises in the float bowl before the float closes the needle valve against the needle seat.

Float system: A carburetion system that provides the correct amount of fuel for all the other systems in the carburetor.

Flywheel: A heavy wheel used to smooth out the power impulses on the crankshaft.

Four-stroke-cycle: A series of events used to develop power in an automobile.

Fuel damper: A component of an EFI system that dampens out fuel pulsations in fuel leaving the electric fuel pump.

Fuel distributor: A component of a continuous-flow EFI system that is connected to an airflow sensor that regulates the amount of fuel flowing to the fuel injectors.

Fuel filter: A device that removes foreign materials from the fuel on its way to the carburetor or fuel injector.

Fuel flow system: An airflow-senstive timed EFI subsystem. Its purpose is to provide the correct amount of fuel (gasoline) to each fuel injector.

Fuel injector: A device that delivers a metered supply of fuel, mixed with the correct amounts of air for efficient combustion in the cylinders.

Fuel lines: Lines that route fuel through the fuel system.

Fuel pump: A pump that draws fuel from the fuel tank and delivers it to the carburetor.

Fuel pump pressure: A measurement of fuel pump output taken with a pressure gage and compared to specifications.

Fuel pump volume: The quantity of fuel a fuel pump can deliver in a specific time period.

Fuel system: The engine system that provides the engine with the correct air-fuel mixture.

Fuel tank: The tank used to store fuel in an automobile.

G

General repair manual: A manual with repair procedures and specifications for vehicles of several years and models.

Graphic mode symbol: Road-sign type of symbols used on graphic mode diagnosis charts to allow the technician to see at a glance (rather than read) exactly what to do.

Ground electrode: The spark plug electrode that is connected to ground. It is also called the side electrode.

H

Heat range: The ability of a spark plug to conduct heat away from its firing end.

Heated intake air system: A system for heating the air that enters the engine to reduce HC emissions, improve warm-up characteristics, and minimize carburetor icing.

Hydrocarbons: A polluting emission that results from incomplete combustion or vapors escaping from the crankcase or fuel system. Hydrocarbons are unburned or partially burned fuel (gasoline). They are abbreviated HC.

Hydrogen: A gas that is given off by a battery and is extremely explosive. It is abbreviated H.

Hydrometer: A glass barrel with a float and a squeeze bulb at the top, used to measure the specific gravity of battery electrolyte.

I

Idle mixture: The mix of air and fuel delivered to the engine during idle.

Idle speed: The RPM of the engine controlled by throttle position, which regulates the amount of air and fuel that enters the engine at idle.

Idle system: A carburetor system that provides the proper air-fuel mixture during engine idling and low speed operation.

Ignition coil: An electrical transformer that uses induction to step up battery voltage for ignition.

Ignition reserve: The difference between available voltage and firing voltage.

Ignition system: A system that provides a series of precisely timed sparks to ignite the air-fuel mixture in the engine's combustion chambers on the power strokes.

Independent garage: An independently owned service facility that may service any type of automobile.

Induction: The transfer of energy from one object to another without the objects being in physical contact with each other.

Infrared exhaust analyzer: A tester that uses an infrared light beam to sample the amount of CO and HC in exhaust gas.

Insulator: A material that prevents the flow of current, or will not act as a conductor.

Intake manifold: A system of pipes that directs the air-fuel mixture to intake ports.

Intake stroke: One of the four strokes of a four-stroke-cycle engine, during which the air-fuel mixture enters the engine.

K

Key switch: A multi-purpose control device whose main function is to control the ignition circuit. It is also called an ignition switch.

L

Lambda probe: A device mounted in the exhaust manifold to monitor the air-fuel ratio. It is usually referred to as an oxygen sensor.

Lead peroxide: The active material that makes up the positive (+) plate.

Light-triggered ignition system: An after-market ignition system that uses a beam of infrared light to trigger the ignition coil.

Limiter caps: Idle mixture control devices that prevent improper adjustment or alteration by limiting the amount of idle mixture screw travel.

Line mechanic: A service worker who may service any part of the automobile.

Load test: A test of battery capacity performed by connecting the battery to an electrical load and observing its voltage.

Lubrication: Reducing engine friction by forcing oil between moving engine parts.

Lubrication specialist: The service worker responsible for performing all lubrication activities.

Lubrication system: An engine system that provides oil to engine parts for lubrication.

M

Magnetism: A force developed when the molecules of a metal are lined up and face in the same direction.

Main gallery: Main oil flow passageway in the cylinder block.

Main metering jet: An accurately machined orifice that controls the flow of fuel in the main metering system.

Main metering system: A carburetor system that controls the middle, or cruising, range of the carburetor.

Manifold pressure sensor: A component of a manifold pressure–sensitive timed EFI system that converts a pneumatic (air) signal into an electrical signal.

Manifold vacuum: Any low pressure below the throttle valve.

Matter: Defined by scientists as "that of which any physical object is composed."

Microfarad: A unit of measure for condenser capacity. It is abbreviated µF.

Microprocessor: An information processor that changes ignition timing based on variables of engine speed and load.

Multiple-barrel carburetor: A carburetor with several venturis and barrels.

N

Negative plates: In a battery, the group of plates negatively charged with electrons.

Neutral safety switch: A switch that prevents the engine from starting unless the transmission is in NEUTRAL or PARK.

O

Ohmmeter: An electrical meter that measures the amount of resistance in a circuit.

Ohm's Law: A law concerning the relationship of electrical elements (voltage, current, and resistance). It states that 1 ampere is equal to the amount of current pushed by 1 volt through a resistance of 1 ohm.

Oil filter: An assembly, usually one-piece construction, that uses a paper element to filter oil before it enters the critical engine parts.

Oil galleries: Oil flow passageways in the cylinder block.

Oil pan: A metal pan mounted to the bottom of the engine that stores lubricating oil.

Oil pump: A gear or rotor device that circulates oil through the lubrication system.

Oscilloscope: A diagnostic tester that traces voltage patterns on a screen.

Overrunning clutch drive: A type of starter motor drive that uses an overrunning clutch to disconnect the drive pinion from the flywheel.

Oxides of nitrogen (NO_x): An emission produced by most forms of combustion, especially at high temperatures. When combined with unburned hydrocarbons (HC) and acted upon by sunlight, it forms smog.

Oxygen sensor: A device mounted in the exhaust manifold to monitor the air-fuel mixture. It is also called a lambda probe.

P

PCV valve: A device that controls the rate at which vapors are allowed to return to the intake manifold of the engine to be ignited with the air-fuel mixture.

Phase difference: An angle, expressed in degrees, between the advance and retard action of a dual point or dual pickup distributor.

Pickup screen: Part of the oil pump that prevents large particles from entering the oil pump.

Pinion gear: The gear driven by the starter motor to rotate the flywheel.

Piston: A round metal part attached to the connecting rod that slides up and down in the cylinder.

Positive crankcase ventilation (PCV) system: A system for clearing the engine crankcase of blow-by gases.

Positive plates: In a battery, the group of plates that give off electrons.

Power balance test: A test in which each cylinder's ignition is grounded or disconnected to determine the power output variation.

Power overlap: The timing of power strokes of different cylinders in an engine for smooth operation.

Power stroke: One of the strokes of a four-stroke-cycle engine, during which power is delivered to the crankshaft.

Power system: A carburetor system that supplements the main metering system.

Pressure regulator: An EFI component that controls fuel pressure.

Primary circuit: The ignition system circuit that carries the low-voltage ignition current.

Primary winding: The part of the ignition coil that consists of a few hundred turns of heavy wire and conducts low-voltage current.

Pulse time: The amount of time measured in milliseconds in which the fuel injectors are open and providing fuel.

R

Radiator: A large heat exchanger which is part of the cooling system and located in front of the engine.

Radiator pressure cap: The cap on top of the radiator. It regulates radiator pressure and vacuum.

Reach: The threaded section of the spark plug shell that determines how far the spark plug fits into the combustion chamber.

Relief valve: A spring-loaded valve that protects the lubrication system from excessive oil pressure.

Resistance: The resistance to current flow in a circuit, measured in ohms.

Reverse polarity: An abnormal condition caused by a reversed connection at the ignition coil primary terminal, an incorrect ignition coil in the vehicle, or a battery that is connected backwards (reversed).

Ring gear: The gear formed by the teeth on the outside of the flywheel.

Rotor: The rotating electromagnet inside an alternator or a part of the ignition distributor.

S

Secondary circuit: The ignition system circuit that carries the high-voltage current used to ignite the air-fuel mixture in the combustion chamber.

Secondary winding: The part of the ignition coil that consists of thousands of turns of fine wire and conducts high-voltage current.

Semiconductor: A material that has the properties of a conductor and an insulator.

Separators: Sheets of insulation placed between the plates of a battery.

Service bulletin: A vehicle manufacturer's one-page or two-page description of a particular service problem and corrective procedure sent to dealerships.

Service label: A source for tune-up specifications, usually located under the hood of the vehicle.

Service (shop) manual: A vehicle manufacturer's manual providing repair procedures and specifications for a particular year and model of vehicle.

Snap acceleration: The quick opening and closing of the throttle valve to load the engine for testing.

Solenoid: A magnetic switch that controls the electrical circuit between the starter motor and battery. It also shifts the pinion gear in and out of mesh with the ring gear.

Spark intensity: The quality, or strength, of the spark produced at the spark plug.

Spark plug: An ignition system component whose primary function is to provide spark to ignite the compressed air-fuel mixture inside the combustion chamber.

Spark plug analysis chart: A chart of common problems that occur at the firing end of spark plugs.

Spark plug cables: Insulated wires that conduct high-voltage current from the distributor cap to the spark plug.

Spark plug code: A code printed on the ceramic insulator to describe its technical features and application.

Spark plug holder: A tray used to hold spark plugs with their terminal ends down. This allows for inspection and comparison.

Spark tester: A tool connected to the end of a spark plug cable to help determine if the ignition system has spark.

Specialist mechanic: A mechanic who works in only one area of service.

Specific gravity test: A test performed with a hydrometer to determine the state of charge of a battery by measuring the specific gravity of the electrolyte.

Sponge lead: The active material that makes up the negative (−) plate.

Spring tension gage: A gage used to measure the spring tension of the movable breaker point arm.

Starter motor amperage draw test: A test to determine how much current the starter motor is using (drawing).

Stator: The three stationary windings in an alternator that are used to generate a voltage.

Surging: An engine performance problem in which engine speed increases and decreases with the same throttle setting.

T

TDC: Abbreviation for top dead center.

Thermostat: A mechanical device in the cooling system that controls the flow of coolant.

Throttle solenoid positioner: A part of the carburetion system that eliminates dieseling, or engine run-on.

Throttle valve: A valve controlled by the throttle (accelerator) linkage that controls engine speed.

Timing light: A tune-up tool used to check and adjust basic timing.

Total advance: The sum of the degrees of advance from basic timing, speed advance, and load advance.

Trouble code: A flashing display on the dashboard which pinpoints a problem in a feedback system.

Troubleshooting: An organized test sequence used to diagnose a problem. It is also referred to as diagnosing.

Troubleshooting chart: A chart listing vehicle problems and the most probable causes for the problems. It is also referred to as a troubleshooting guide, diagnosis chart, or diagnosis guide.

TVRS: Letters on a spark plug cable indicating a design that eliminates radio frequency interference (RFI).

V

Vacuum: A pressure lower than atmospheric pressure.

Vacuum advance mechanism: An ignition timing component that is sensitive to engine load and uses engine vacuum to advance the ignition spark.

Vacuum gage: A tool used to measure the amount of vacuum in the vacuum circuit or in the intake manifold of an engine.

Vacuum pump: A hand-operated pump used to create a vacuum to test vacuum-operated systems and parts.

Valve lash: The space, or clearance, in a mechanical valve train that provides for expansion. It is also referred to as valve clearance.

Valve overlap: A short period of time when both valves are open.

Valve train: An assembly of engine parts that open and close the passageways for the intake of air and fuel as well as for the exhaust of burned gases.

Vaporization: Turning liquid fuel into a gas or vapor.

Vapor canister: A component of the evaporation control system that absorbs fuel vapors from the fuel tank and carburetor and retains them until they can be drawn into the intake manifold when the engine is running.

Vehicle emission control information label: An under-the-hood label that describes the type of emission equipment and specifications for that vehicle.

Venturi: A construction in the carburetor barrel.

VIN: Abbreviation for vehicle identification number. It is used when looking up vehicle specifications.

Voltage: The amount of electrical pressure in a circuit, measured in volts.

Voltage regulator: A charging system component that limits current flow in the field coil of the rotor and controls alternator output.

Voltmeter: An electrical meter that measures the amount of voltage in an electrical circuit.

W

Water jackets: Passages in the cylinder block and head for coolant flow.

Wire feeler gage: A set of precision-ground wires used to measure the air gap of spark plugs.

Wire size: The size of a wire based upon the diameter and circular mil area of a round conductor center core.

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DATE DUE

~~MAY 1 0 '86~~			
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JUN 2 8 [illegible]			
OCT. 1 1 1988			
AUG. 22 1988			
OCT. 2 7 1993			
GAYLORD			PRI

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TL210.W38 1983
Webster, Jay. 010200 000
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ISBN: 0-8269-0256-1